INVESTIGATING AN ONLINE PROJECT BASED PROFESSIONAL DEVELOPMENT COURSE FOR TEACHERS IN SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS

by
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Abstract

The purpose of this descriptive case study using a convergent mixed methods design was to analyze teachers' perceptions of an online science, technology, engineering, and mathematics (STEM) PD course. The following three research questions helped guide the study: (a) what are teachers' perceptions of an online STEM professional development course, (b) how do teachers describe their confidence in implementing a STEM curriculum after an online professional development course, and (c) what components of an online professional development course are perceived as supports and barriers for teachers' in acquiring pedagogical and content knowledge. Study participants included both PD facilitators and participating teachers who work in schools that have adopted the new STEM curriculum. Data for the study included the organization's archival records (course satisfaction survey responses), and transcripts from semistructured interviews. Online classroom observations and a researcher's journal supplemented the main data. Descriptive quantitative analyses were conducted of data from satisfaction surveys and observations. Thematic analysis was used to identify themes within all open-ended response survey questions, interview responses, classroom observations and researcher's journal entries. Analyses indicated that participants were satisfied overall with the course and their level of satisfaction was dependent on the quality of instruction of their facilitators. Participants identified supports in aquiring pedagogical and content knowledge as facilitators' availability, shared resources and hands-on demonstrations by the facilitator, and experiencing curricular activities as students; they identified barriers as course technology issues, irrelevant additions to the course, and disorganized breakout rooms. Overall, participants felt more confident returning to their classroom when they had the necessary resources to teach new skills. The dissertation concludes with several recommendations for improving PD participants' experience in the online course.

Keywords: Online teacher professional development; Online course design; Project-based learning; Science, technology, engineering and mathematics; Teacher online learning.

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The student has made all necessary revisions, and we have read, and approve this dissertation for submission to the Johns Hopkins Sheridan Libraries as partial fulfillment of the requirements for the Doctor of Education degree.

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Dedication

I have learned so much throughout this education journey. This work is dedicated to my parents and my daughter for their unconditional support and love. To my parents, Pedro and Yolanda Baquet, who instilled the value of education, the importance of a strong work ethic, and without whom none of my success would be possible. To my sweet angel Sophie, I will always make time to spend with you, and thank you for distracting me from my work when I needed it the most.

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Executive Summary

Given that teacher effectiveness is directly tied to student outcomes, there is an ongoing need to improve the effectiveness of teachers through quality, targeted professional development (PD) since the effectiveness of the teacher is directly tied to student learning and achievement outcomes (Dede, 2006; Fishman, Marx, Best, & Tal, 2003; Jaquith, Mindich, Wei, & Darling-Hammond, 2010). Student outcomes depend on good instruction, and good instruction depends on teachers receiving quality PD (Desimone & Garet, 2015; Guskey, 2000). Unfortunately, PD programs are presently not sufficiently addressing the needs of teachers in ways that lead to changes in instructional practice both generally and for STEM specifically (Darling-Hammond, Hyler, & Gardner, 2017). Additionally, PD is often of poor quality and superficial (Borko, 2004) and it often does not provide flexible times to fit into teachers' schedules (Dede, Ketelhut, Whitehouse, Breit, & McCloskey, 2009). Because of their different experiences, teachers have diverse needs that are not always being addressed in how PD is delivered to them (Bill & Melinda Gates Foundation, 2014). In particular, given the growth in online PD programs, there is a need to improve the design and delivery of these programs, particularly in STEM PD.

Although there is a growing body of literature on supports and barriers that exist in the design and implementation of online programs, there is only a limited focus on online STEM PD. This mixed methods study focused on describing STEM teachers' experiences following their participation in a 10-week online STEM course. Specifically, it addressed teachers' perceptions of the course design, what components of the online course served as supports and barriers for them to acquire the pedagogical and content knowledge, and their confidence in teaching after receiving the PD.

Context

The context for this study was the online Design and Modeling course offered by Project Lead the Way (PLTW), a non-profit educational organization that offers a proprietary STEM curriculum and also creates and delivers their own STEM PD courses for grades K-12 nationwide. The online Design and Modeling STEM course was delivered by two lead PD facilitators, and one tech support facilitator. The course was taught using the web conferencing tool Zoom. Each class met weekly for a two-hour synchronous session over a ten-week period.

Purpose and Methodology

The purpose of this study was to address the following research questions:

RQ1: What are teachers' perceptions of an online STEM professional development course?

RQ2: What components of an online professional development course function as supports and barriers for teachers in acquiring pedagogical and content knowledge?

RQ3: How do teachers describe their confidence in implementing a STEM curriculum after an online professional development course?

This descriptive case study used a mixed methods approach with a sequential research design.

Participants

A total of approximately 403 teachers, participated in the online STEM PD course during the 2018 or 2019 trainings. There were six Fall 2018 cohorts, two Spring 2018 cohorts and six Fall 2019 cohorts with approximately 30 participants in each cohort. Each cohort was taught by three PLTW PD facilitators (two lead teachers and one tech support coach), a total of approximately 21 PD facilitators. Several PD facilitators taught more than one cohort.

All participants and facilitators that were part of the 2018 and 2019 Fall online Design and Modeling classes were invited to participate in the study. Out of the 26 participants that responded to the invitation, 18 participated in both the survey and the interview. All six PD facilitators that responded to the invitation all six participated in the interview.

Data Collection and Analysis

The data collected in this study consisted of archival records (PLTW's satisfaction survey), post-PD semistructured interviews, online classroom observations, and the researcher's journal. Non-archival data collection began in August of 2019 and ended in December of 2019. At the end of the course all participants were asked to complete PLTW's satisfaction survey. The quantitative portion of PLTW's survey was analyzed using descriptive statistics while the open-ended responses were analyzed with thematic coding. Semistructured interviews were conducted and recorded over the phone or using Zoom, a web conferencing tool, and then the audio recordings were transcribed and analyzed with thematic coding under the constructs of course design, pedagogical and content knowledge and teacher confidence. Online classrooms observations were conducted during the ten-week sessions using an online observation protocol, in addition to field notes recorded in the researcher's journal.

Findings

The descriptive study data revealed that teachers felt most satisfied with the online STEM PD course when their course was well designed, the pedagogical and content knowledge was well balanced, and when teachers were offered adequate opportunities to practice the new skills in order to build their confidence to return to their classrooms and teach the newly adopted curriculum. Analyses indicated that teachers' experience was dependent on their facilitator. Teachers felt they learned best from a facilitator that engaged with them by offering

guided demonstrations on how to implement the new material, and felt more confident to teach the new STEM curriculum after having adequate practice time. The research found that disorganized and unmonitored breakout rooms led to confusion and hindered teachers' learning. Teachers noted challenges with the learning management system used to upload and download assignments. Recommendations include choice of a different learning management system to better serve participating teachers, design of prerequisite learning modules, and training of facilitators to provide more common, coherent experience across sections.

Chapter 1

Understanding the Problem of Practice

The need for improvements in student achievement outcomes is evident in the results of international assessments such as the 2015 Program for International Students Assessment (PISA), which showed the United States performing near average in science and reading and below average in mathematics in the 2015 survey conducted by the Organization for Economic Co-operation and Development (OECD, 2016). The National Assessment of Educational Progress (NAEP) findings show that far less than half of students are proficient, and even fewer among low-income students and students of color in mathematics (NAEP, 2017). As student achievement outcomes continue to flatline, the gaps between the low socioeconomic status students and the wealthier students continue to widen (Darling-Hammond, 2000; OECD, 2016; U.S. Department of Education, Office of Innovation and Improvement, 2016). These inequities also exist in "access, participation, and success in science, technology, engineering, and math (STEM)" among underrepresented minority groups (U.S. Department of Education, Office of Innovation and Improvement, 2016, p. i). One of the ways to meet students' needs and raise their achievement is through quality instructional practices (Blazar, 2015; Darling-Hammond 2000; Grossman, Loeb, Cohen, Hammerness, Wyckoff, Boyd, & Lankford, 2010). There also exists international evidence that quality teaching has a significant effect on student achievement outcomes. The OECD administered Teaching and Learning International Survey (TALIS) results show that teachers in countries that receive helpful PD, useful feedback and more time to collaborate to improve their work improve student achievement (OECD, 2014).

Instructional Quality and Student Achievement Outcomes

Research supports the link between instructional quality and student achievement outcomes (Chetty, Friedmand, & Rockoff, 2014; Darling-Hammond, 2000; Goe, 2007). Darling-Hammond (2000) found that not only did the least experienced and prepared teachers teach the least advantaged students but that underprepared teachers decrease student achievement outcomes. Grossman et al. (2010) conducted a pilot study to assess if instruction affected student achievement based on test score performance. They asked "what classroom practices, if any, differentiate between teachers with high impact on student achieving in middle school English/Language Arts, as measured through value-added analyses, from teachers with lower low value-added scores?" (Grossman et al., 2010, p. 2). Through classroom observations they found that instructional quality using effective strategy instruction, such as teaching how to master skills rather than simply completing tasks, improves student achievement in writing and reading.

Quality teaching has also shown gains in student achievement outcomes in mathematics. Blazar's (2015) study sought to identify classroom practices that support student achievement. He found a strong correlation between teachers' content knowledge and their ability to present correct material in class (Blazar, 2015). His results show a significant relationship between instructional quality and students' mathematics achievement. Prior research also indicates that instructional qualities such as high content knowledge lead to student achievement (Boyd, Grossman, Lankford, Loeb, & Wyckoff, 2009; Darling-Hammond, 2000; Metzler & Woessmann, 2012; Shulman, 1986). These findings can inform PD efforts aimed at raising quality of instruction and student achievement. In order to continue working towards improving student achievement outcomes we must continue examining teacher training to find ways that

will lead to effective teacher practices to improve student achievement outcomes (Desimone, 2009; Desimone et al., 2015; Kane, McCaffrey, Miller, & Staiger, 2013).

Instructional Quality and Teacher Professional Development

Just as doctors need to continue their professional growth in order to serve the public, teachers need to continue improving their skills to serve their students. Effective PD is defined as that which is structured to allow for improvement in both teacher practices and student achievement (Darling-Hammond, et al., 2017). By building their instructional quality through effective PD, teachers will in turn build their confidence when teaching their students (Ertmer & Ottenbreit-Leftwich, 2010; Jameson & Fusco, 2014). Recent research has shown statistical evidence for how effective PD improves student achievement outcomes (DeMonte, 2013; Heller, Daehler, Wong, Shinohara, & Miratrix, 2012; Polly, McGee, Wang, Martin, Lambert, & Pugalee, 2015; Yoon, Duncan, Lee, Scarloss, & Shapley, 2007). In addition to these empirical studies, two meta-analyses have contributed to the body of literature by also showing empirical evidence demonstrating how effective PD does improve teacher practices and in turn improves student outcomes (Blank & de las Alas, 2009; Garsten, Taylor, Keys, Rolfhus, & Newman-Gonchar, 2014).

The State of Professional Development

Although there is empirical research that links effective PD to both instructional quality and student achievement, there is also research that shows that PD does not always (or even usually) impact instructional quality to raise student outcomes (Darling-Hammond, 2000). Fullan (2007) argues that PD opportunities are not adequate enough to lead to changes in instructional practice or student achievement. Indeed, Darling-Hammond et al. (2017) and Penuel, Fishman, Yamaguchi and Gallagher (2007) point out that most recent research shows

ineffective strategies such as teachers receiving PD in short trainings. PD in general is poorly delivered in terms of its ability to energize and transform the teaching experience (Guskey & Yoon, 2009). Most PD is done in the context of school, takes place at odd hours, usually after school, and is directed at whatever agenda the administration has on its mind (Avalos, 2011; Darling-Hammond, et al., 2017; Desimone et al., 2015; Garet, Porter, Desimone, Birman, & Yoon, 2001). The Bill and Melinda Gates Foundation published a thorough report, *Teachers Know Best,* that states that even though $18 billion is invested annually on teacher PD, teachers' needs are not being met (Bill & Melinda Gates Foundation, 2014). Teachers understand what they need from PD. The teacher survey responses from the *Teachers Know Best* report show that teachers need their PD to be "relevant, interactive, delivered by someone who understands their experience, sustained over time, and treats teachers like professionals" (Bill & Melinda Gates Foundation, 2014, p. 4). Given the amount of resources spent on PD, it is crucial to understand how to structure PD so that it will help improve instructional quality and increases in student achievement (Jacob, McGovern, 2015; Whitworth & Chiu, 2015).

The State of STEM Professional Development

Instructional quality depends on teachers receiving PD support in their specific content areas. STEM teachers need PD that helps them continue to improve their skills in technology, pedagogy and content knowledge (TPACK) to prepare for 21st century instruction (Grable, Molyneaux, Dixon, & Holbert, 2011; McPherson & Anid, 2014; Srisawasdi, 2012). TPACK provides a theoretical model that explains the application of problem-based learning that may be found in quality STEM PD (Parker, Stylinski, Bonney, Schillaci, & McAuliffe, 2015). STEM teachers also need opportunities to learn how to integrate STEM concepts in the classroom (Honey, Pearson, & Schweingruber, 2014). However, STEM teachers often do not find adequate

PD that leads to changes in instructional practices (Volmert, Baran, Kendall-Taylor, & O'Neil, 2013). Most STEM PD offers teachers conceptual knowledge with little to no time to apply what they have learned. Additionally, STEM PD rarely addresses issues of student engagement and how to integrate technology effectively to increase student achievement outcomes (Ertmer et al., 2010; Nadelson, Callahan, Pyke, Hay, Dance, & Pfiester, 2013). PD is seldom focused on the things that matter most to STEM teachers: creating vibrant learning environments infused with the technology current students use as a matter of routine (Avery & Reeve, 2013; Lawless & Pellegrino, 2007). Teachers often believe they are not proficient in modern technology tools and do not have the knowledge needed to deepen student learning (Ertmer et al., 2010). Teachers also have little time to stay current with technology trends in the teaching of their discipline or grade level to increase their TPACK skills (Jimoyiannis, 2010; Lim, Zhao, Tondeur, Chai, & Tsai, 2013).

Online Professional Development Is Not Meeting Teachers' Needs

Due to the lack of local resources, schools are finding alternative and more cost-effective ways to deliver teacher trainings. Online PD is widely being adopted by schools throughout the United States and is becoming increasingly popular (Dede, 2006). Teachers are finding online PD to be more cost-effective and provide them with more flexibility in their schedule to accommodate PD, a full-time job, and family responsibilities (Dede, 2006). However, online PD may pose challenges to teachers' learning and may also not be meeting teachers' needs in quality of instruction in STEM. Teachers participating in online PD not only need to know how to use their own technology, but they also need to learn the technology that is being used by the PD facilitator in addition to the new content that is being taught; this can be a daunting and overwhelming task (Doering, Veletsianos, Scharber, & Miller, 2009). Online PD demands that

teachers have a whole skill-set for learning such as self-regulation and organizational skills (Dede et al., 2009). Other skills, such as self-motivation, reflecting, setting goals, and asking for help when needed, all contribute to online teacher learners' success (Rienties, Brouwer, & Lygo-Baker, 2013; Russell, Carey, Kleiman, & Venable, 2009). Additionally, STEM teachers may find online PD more difficult due to the problem-based and hands on nature of the subject in an environment where there is minimal direct or immediate communication and feedback with the instructor (Dede, Eisenkraft, Frumin, & Hartley, 2016; Fishman, 2016).

Study Outline

This study will examine perceptions of an online STEM PD program implemented by the non-profit organization PLTW. Chapter 2 provides a theoretical framework and literature review. In Chapter 3 background information is provided to understand how PTLW's PD courses are structured and how they are delivered to STEM teachers. Chapter 4 explains the methodology of the study including the purpose, research design, data analysis, and researcher positionality. Chapter 5 reports the findings and Chapter 6 discusses and connects the findings with the research literature. The dissertation concludes with several recommendations for PLTW regarding how to make the online STEM PD even more effective.

Chapter 2

Overview of Theories and Literature Review

To understand the factors that help to explain why PD often does not sufficiently address the needs of teachers, it is useful to examine the problem through the lenses of both Knowles' andragogy framework (Knowles, 1978) and the systems framework for PD described by Borko (2004). Knowles's (1978, 1984) andragogy framework describes the specific needs of adult learners that motivates them to learn. Borko's (2004) conceptual framework situates the teacher, PD program, and the facilitator within the context in which the PD occurs as shown in Figure 2.1. The literature on PD will be analyzed within the PD system framework articulated by Borko (2004) using an andragogical lens.

Theoretical Framework

Andragogy as a Theoretical Framework

Teachers have specific needs as adults. Malcolm Knowles, known as the father of andragogy in the United States, began the discussions around the framework and described it as a parallel to pedagogy but for adult learners (Knowles, 1978; Knowles, 1984, Knowles, Holton, & Swanson, 2011). Although there is literature that identifies andragogy as a theoretical framework (Harris, 2000; Knowles, 1978; Knowles, Holton, & Swanson, 2011), some argue that it has not been field tested extensively (Boulton-Lewis et al., 1996; St. Clair, 2002). These researchers describe it as a conceptual framework model while others describe andragogy as both a theoretical and conceptual framework interchangeably (Knowles et al., 2011; Merriam, 2001). Describing adults as responsible for their own learning and self-directed, Knowles states that "adult education is an attempt to discover a new method and create a new incentive for learning" (Knowles, 1978, p. 11). In this dissertation, andragogy will be the common thread used as a

theoretical framework to understand what adult learners need from PD to learn effectively. Knowles describes six assumptions about adult learning: (a) adults need to know why they need to learn something, (b) adults need to be involved in making decisions in order to be a self-directed learner, (c) adults need to learn by experimenting, (d) adults need to know they can apply what they are learning immediately, (e) adults approach learning as problem-solving, they need to learn skills and acquire knowledge in context and, (f) adults need to be intrinsically motivated (Knowles, 1984). Adults learn differently and have different needs than children. Knowles' six assumptions can provide a framework to understand what teachers need as adult learners in their PD experience.

Conceptualizing Professional Development as a System

In addition to this andragogical framework, it is useful to situate PD within a systems framework. Borko's (2004) conceptualization of the PD system includes the teacher as an adult learner, who interacts with facilitators (PD instructors) and the PD program (the content and learning activities) within the context (educational system). In the following section I use this framework to explore the literature on factors that are associated with the problem of PD that is not sufficiently meeting the needs of teachers. I begin with the context in which PD occurs, and then explore teacher and facilitator factors. I then explore the malleable PD program factors that affect teachers' learning experiences.

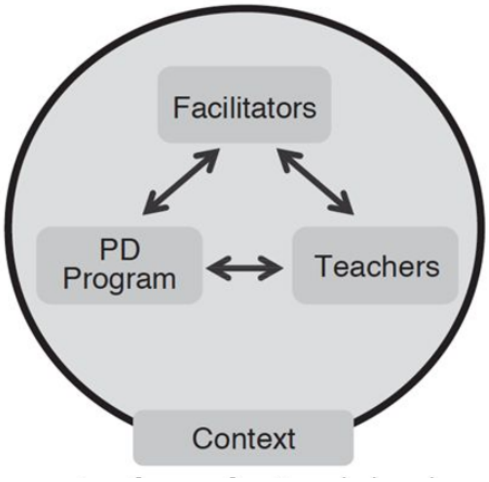

Figure 2.1. Four elements of Borko's PD system. From "Professional development and teacher learning: Mapping the terrain," by H. Borko, 2004, *Educational Researcher, 33*, p. 4. Copyright 2004 by the American Educational Research Association. Reprinted with permission from the author.

Underlying Factors Affecting Teachers' Professional Learning

Context Factors

It is crucial to understand how contextual factors affect teachers' professional learning in order to identify those characteristics that lead to instructional quality and ultimately student achievement. The contextual factors associated with PD not sufficiently addressing needs of teachers include federal and state policies, district level factors, school level factors and the external PD provider context.

Federal and state policies. The emphasis on student outcomes in federal and state policies is a key contextual factor for teacher PD (Phillips, Desimone, & Smith, 2011). The No Child Left Behind (NCLB) Act passed by Congress in 2001 held schools and teachers accountable for student performance on standardized tests (McGuinn, 2006). However, the educational community believed that the federal act was unfair to expect schools to fix issues

that were rooted in socioeconomic disparities (Hartney & Flavin, 2011). Race to the Top (RTTT), introduced in 2009 (U.S. Department of Education, 2009), focused on school improvement grants through a competitive process that focused on innovation. However, these aggressive school reforms led to political backlash against the federal government's involvement in education (McGuinn, 2016). In 2015, the Every Student Succeeds Act (ESSA) trimmed back the role the federal government played in education and provided school districts with more flexibility on how to intervene with improvement schools (bottom five percent of Title I schools) (McGuinn, 2016). The ESSA focused on promoting innovation, resource allocation and distribution of quality teachers (Simon, 2014). Therefore, in 2015 the STEM Education Act became a law encouraging schools to use portions of their funds for STEM initiatives including STEM PD for teachers (STEM Education Act of 2015).

These educational reforms, driven by political agendas, have required standardized testing to measure student, teacher and school achievement and have provoked complaints on the part of teachers that they must teach to the test, leaving little room for teaching and learning in STEM (Darling-Hammond, 2016). These high-stakes testing programs created an environment not conducive to teachers' professional growth, as so much of allocated PD time is focused on test preparation (Kyriacou, 2001).

Despite the established need for STEM education, the changing winds of politics can imperil funding crucial to this effort. Although programs such as Investing in Innovation, the Teacher Incentive Fund, the Math and Science Partnerships program, Teachers for a Competitive Tomorrow, and the Teacher Quality Partnerships program were put in place to assist educators in STEM teaching and learning and provide PD opportunities (U.S. Department of Education,

Office of Innovation and Improvement, 2016), they could be dismantled by a forthcoming administration, as our educational system is highly influenced by politics (Cuban, 2003).

State policies influence teachers' participation in PD which ultimately affect instruction and student outcomes (Bryk, Sebring, Kerbow, Rollow, & Easton, 1998; Fullan, 2007; Sebring & Bryk, 2000). Although there is a limited amount of research on those attributes of state policies that lead to improvements in teaching and learning (Spillane & Louis 2002), the body of literature suggests that when state policies align and are consistent with those at the district and school level there is greater teacher participation in content-focused PD (Phillips et al., 2011). A study by Phillips et al. (2011, p. 2613) demonstrated that consistent state and school policies motivate teachers to partake in the "type of PD that is mostly associated with improved teacher and learning."

District level factors affecting PD experience. School districts nationwide invest in ongoing teacher PD in order to raise student achievement (Mizell 2010; Whitworth, Maeng, Wheeler, & Chiu, 2017). As a major provider, they spend thousands of dollars on PD per teacher to advance their learning (Birman et al., 2007; Pianta, 2011; Spillane, 2002). School districts are mandated at the state level as to how many hours of PD teachers need to take for state recertification in their subject area in order to remain employed. However, many school districts schedule very few days within the academic year to complete all of the PD hours that are required, leaving teachers to complete the required hours during their weekends or afterschool. Unfortunately, many of these PD sessions tend to be of short duration with little to no follow-up support (Loucks-Horsely & Matsumoto, 1999; Pianta, 2011) and not content-focused (Spillane, 2002). These short PD sessions often are ineffective, as they address

administrative or discipline issues rather than content-focused material (Desimone, Smith, & Phillips, 2007; Pianta, 2011).

There is also evidence that shows that districts can have a positive impact on instruction through quality PD that is both coherent and content focused (Desimone, Porter, Garet, Yoon, & Birman, 2002; Firestone, Mangin, Martinez, & Plovsky, 2005). District leaders, such as superintendents that made decisions based on research-based data, were actively involved in curricular changes and its implementation, and supported schools' autonomy, helped raise student performance in 12 school districts in California (Murphy & Hallinger, 1988). A meta-analysis based on 69 empirical studies over a 30-year span found high correlations between effective leadership and student achievement (Marzano, Waters, & McNulty, 2005). Leadership characteristics correlated highly with achievement included: forming well-defined and concreate goals, building professional communities, creating opportunities for collaboration, and fostering a collaborative school culture (Copland & Knapp, 2006; Marzano et al, 2005). It is clear that effective leadership at the district level includes supporting teachers' professional growth as a means to improve support instructional quality and student achievement (Birman et al., 2007; Leithwood, Seashore-Lois, Anderson, & Wahlstrom, 2004; Pianta, 2011).

School level factors affecting PD experience. Effective PD programs take teacher needs into consideration. These include understanding how the adult brain is best engaged under low stress and how to empower adults to be self-directed and highly motivated (Chametzky, 2014; Cozolino & Sprokay, 2006; Darden, 2014). School schedules are often an issue allowing little to no time for collaborative PD during the school day. A school's collaborative culture influences teacher change and classroom practices (Bianchini & Cavazos, 2007). In one case study a school's collaborative culture was an important factor in determining if teachers were

going to implement a reformed math and science curriculum learned in their PD (McGinnis, Parker, & Graeber, 2004). Teachers who perceived a supportive school culture with opportunities to collaborate carried out the reform-aligned curricular changes, and on the other hand teachers resisted to implementing curricular changes when they perceived a lack of support (McGinnis et al., 2004). A school's collaborative culture is necessary to establish professional learning communities (Grossman, Wineburg, & Woolworth, 2000) which allow teachers to share new ideas and classroom practices (Lakshmanan, Heath, Perlmutter, & Elder, 2011). Additionally, schools that carve out time for teacher collaboration after PD activities support mentoring and coaching (Luft & Hewson, 2014). Mentoring and coaching can help teachers strategize on how to integrate new practices and knowledge learned from their PD experiences (Grierson & Woloshyn, 2013).

External PD provider context. The amount of teacher PD provided by external providers has been estimated at $3 billion of the 18 billion spent annually by U.S. districts (Bill & Melinda Gates Foundation, 2014). External PD providers do not always meet the situated needs of teachers in their school and professional community. Evidence shows that often external providers do not understand the teachers' instructional context and are also not there to provide follow-up assistance to teachers (Newmann, King, & Youngs, 2000). This can leave teachers unmotivated and unsupported to change their teaching practices. The study by Newmann et al. (2000) compared nine schools. Some schools had their PD program delivered by several external providers and in other schools the PD program was created and delivered school-wide in-house (Newmann et al., 2000). The results showed that teachers who participated in the school-created PD examined their pedagogy, shared classroom practices in collaborative grade level meetings and had a greater sense of confidence in teaching the newly learned skills.

This study shows that knowing the school context is critical in developing an effective PD program that will lead to changes in classroom practices (Newmann et al., 2000). Additionally, external providers usually have a fixed agenda with a large amount of content material that needs to be delivered within a short period of time. This lack of extended duration does not allow teachers to collaborate or reflect with colleagues (Desimone, 2009), a dimension of PD that has been shown to have a significant correlation with student achievement (Johnson, Kahle, & Fargo, 2007).

Teacher Factors

Because teachers are situated in diverse contexts, they have diverse needs. As adult learners, teachers also bring diverse individual backgrounds and experiences when they participate in PD activities. These influences include prior experiences with technology use, pedagogy, content knowledge and the integration of these, as well as their confidence in teaching (Borko, 2004).

Teacher experiences. Teachers' PD preparation begins during their preservice training and continues throughout their career. They have a variety of prior PD and teaching experiences that not only can affect their learning during PD sessions but also contribute to whether they will implement what they have learned. As adult learners, teachers also have multiple responsibilities including those outside of the classroom and they do not want to invest their time on irrelevant learning that does not align with their immediate context (Imel, 1995). It is important to understand that teachers have different needs depending on their prior experiences and their context. Teachers also know what they want in their PD experiences. They want to learn new skills and acquire knowledge they can put to use in their classrooms to help their students

(Knowles, 1984) and they need to be given time to practice the new skills or content (Desimone, 2009) so they feel confident returning to their classrooms.

Teacher knowledge. Teachers' prior knowledge plays an important role in their learning (Minor, Desimone, Lee & Hochberg, 2016). According to Shulman (1986) there are various knowledge domains that researchers take into consideration for quality instruction: (a) subject-matter knowledge, (b) pedagogical content knowledge (PCK), and (c) curricular knowledge. Teacher knowledge gains have been shown to be associated with teachers' college major, years of experience, certification, and test scores (Phillips, et al., 2011; Sadler, Sonnert, Coyle, Cook-Smith, & Miller, 2013). In Mishra's and Koehler (2006) TPACK framework teachers' pedagogical knowledge, content knowledge, and technology knowledge were combined to demonstrate how teachers' knowledge is associated with the effective use of technology (Graham et al., 2009; Koehler, Mishra, Kereluik, Shin, & Graham, 2014; Koehler, Shin, & Mishra, 2012).

PCK is the combination of pedagogy and content knowledge. Shulman (1986) conceptualizes PCK as teaching knowledge that is content-specific. Teachers' PCK includes a balanced array of attributes that cover content-specific curricula and how to best teach it to maximize learning. Teachers' PCK attributes include an awareness of the knowledge their students bring with them, an understanding of common content-related misconceptions, different teaching strategies of the content, and a variety of ways on how to address content-specific problems (Harris, Mishra, & Koehler, 2009).

Unlike other areas, STEM is content-rich, with teachers having to master a great deal of factual information in order to be able to teach the skills. A study that explored how teacher content knowledge affects what they learn and apply from PD showed that effective PD needs to

take teachers' prior content knowledge into consideration (Minor et al., 2016). The findings from the study suggest differentiating PD depending on teachers' knowledge and diverse needs (Minor et al., 2016). Another study showed that prior teachers' content knowledge is difficult to change and may require more PD time (Garet et al., 2010, Garet et al., 2011). Research also shows that teachers find it easier to change routines or procedures rather than acquire new content knowledge and apply it in meaningful ways (Desimone et al., 2015; Garet et al., 2010, Garet et al., 2011; Piasta et al., 2010).

Teacher self-efficacy. Bandura (1986) emphasized the importance of self-efficacy, which he distinguished from the more general concept of confidence and defined as "people's beliefs in their capabilities to produce given attainments" (Bandura, 2006, p. 307). Self-efficacy is a "context-specific judgement" Bandura (1986) as cited in (Pajares & Miller, 1995, p. 196) and is task dependent. There is evidence that teachers with higher self-efficacy are more likely to be willing to change their practice (Tschannen-Moran, Hoy, & Hoy, 1998). This could also mean that PD is not really impacting teachers with low self-efficacy, and should be considered in planning more effective PD. Evidence shows that PD done over a sustained period increases the self-efficacy of teachers with lower self-efficacy at baseline (Roberts, Henson, Tharp, & Moreno, 2000). There is also evidence that effective PD can increase teacher self-efficacy (Tschannen-Moran et al., 1998) and student achievement (Tschannen-Moran & Barr, 2004). In another study self-efficacy was increased as a result of science teachers developing their content knowledge (Lakshmanan et al., 2011).

Most teachers, even those who teach in the STEM field, are not as facile with educational technology as one might think. Their ability to use this technology is tied to their own self-efficacy especially when they fear that some of their students may be farther along than they are

in terms of the use of technology (Ertmer et al., 2010). As noted in one STEM PD study (Nadelson et al., 2013), teachers had an increased sense of self-efficacy in integrating technology into their classrooms after participating in a STEM PD program that continued over a two-year period. This study also concluded that teachers need to be given adequate time to learn how to integrate the content into their day-to-day classroom practices (Nadelson et al., 2013). Teachers need to be taught how not just to use technology but how to integrate it into their classrooms in meaningful ways (Mundy, Kupczynski, & Kee, 2012). Coaching in collaborative ways such as group discussions may help teachers raise their self-efficacy in integrating new skills in their classroom practices. (Desimone, 2009).

Facilitator Factors

Just like teachers play an important role in students learning experience, the facilitator also plays an important role in the teachers' PD experience (Park, Johnson, Vath, Kubitskey, & Fishman, 2013). Teachers describe their ideal PD experience as one delivered by a facilitator that understands their context – who has experienced classroom teaching personally. Teachers want PD facilitators who treat them as adults (Bill & Melinda Gates Foundation, 2014; Blackley & Sheffield, 2015). Given the need for more sustained, ongoing PD experiences, it may also be important for the PD facilitator to be frequently accessible. There is little research literature dedicated to the PD facilitator; however, there is some emerging literature that is beginning to focus on the online PD facilitator and the online learners (Garrison, Anderson, & Archer, 2000; Lu & Jeng, 2006). Park et al. (2013) defined the role of the PD facilitator in a face-to-face PD setting compared to an online PD workshop and their interactions with the adult learners. In their study, they found that facilitators in an online environment can work with their participants more on a one-to-one basis; however, they need to put forth more effort inviting the teachers to

participate in discussions (Park et al, 2013). PD facilitators also need to assess the online participants' content knowledge and understanding, thereby providing participants more attention to meet their needs (Park et al., 2013).

Another study showed that teachers participating in PD constructed their knowledge when their facilitator participated in online discourse that confirmed their knowledge (Lu et al., 2006). Teachers need PD facilitators that help them build their self-efficacy during their courses, which will in turn build their confidence when returning to their classrooms to teach their students (Ertmer et al., 2010; Jameson et al., 2014).

STEM teachers need PD facilitators that are skilled in TPACK. They need good content area knowledge and skills like knowing how to conduct procedures using technology with ease and success. They must also know how to teach the material to successfully integrate the technology and content in a pedagogically sound manner (Harris et al., 2009; Matherson, Wilson & Wright, 2014; Thomas, Herring, Redmond, & Smaldino, 2013).

PD Program Factors

Structure of learning. In the last decade researchers have contributed to the body of literature with empirical evidence on what constitutes effective PD. Desimone (2009) developed a conceptual framework that includes five features for effective PD. The five features are: (a) content focus, (b) active learning, (c) coherence, (d) sustained duration, and (e) collective participation. These are theorized to lead to changes in teacher beliefs, attitudes, and knowledge to changed instructional practices and improved student achievement (see Figure 2.2).

Content focus. An effective PD program design should be content-focused, offering pedagogical and content knowledge and demonstrating how the content should be taught for better student understanding. The PD should include the opportunity for teachers to analyze

student work in the specific subject areas in order for teachers to understand how students lean and process the content. Several studies that have shown increases in teacher knowledge through participation in content-focused PD (Allen & Penuel, 2015; Fishman et al., 2013; Garet et al., 2001; Penuel et al., 2007; Roth et al., 2011).

Active learning. Active learning in effective PD includes teachers working with the tools and materials to gain practical experiences. It could also include teachers developing ideas and presenting lessons or concepts to others. Active learning is the opposite of passive learning such as listening to a lecture or watching a PowerPoint presentation for the duration of the PD session. Teachers should be given opportunities to engage with inquiry-based activities and to reflect on how to integrate their learning and their practices (Borko et al., 2010).

Coherence. Coherence in effective PD is ensuring that what is taught in PD sessions is consistent with the school district's and the school's goals and policies. Coherence in effective PD also suggests that there is consistency between the PD content and teachers' beliefs, knowledge and students' needs. Knapp (2003) also suggests that PD goals set by schools should be congruent with teachers' prior knowledge and their diverse needs. Evidence shows that teachers indicated that they would be more responsive to implementing activities in which they perceived a coherent PD program that met their teacher needs and their "goals for their students' learning" (Penuel et al., 2007, p. 952).

Sustained duration. Sustained duration refers to the number of hours and the span of that time (throughout the school year or in a three-day workshop) in which the activities are performed. Desimone (2009) suggests 20 contact hours, Yoon et al. (2007) suggest at least 14 hours, and Supovitz and Turner (2000) suggest 80 hours; however, the consensus is that long-term PD with ongoing support is most effective for producing changes in teacher practices.

Unfortunately, because of budget constraints, lack of time, and poor leadership, teachers are attending short PD workshops that have little to no effect on teacher practices and student achievement (Yoon et al., 2007).

The duration of time in PD experiences is a recurring factor described in the literature in reference to the time dedicated to the PD experience and the time dedicated to practice the new knowledge learned by participants (Penuel et al., 2007). When teachers are given time to reflect (Gerstein, 2013) and to collaborate on practical ways to implement the new skills and knowledge learned they have a greater sense of self-efficacy in teaching their students.

Collective participation. Collective participation in PD offers teachers opportunities to collaborate, have discussions, and learn from the facilitator and peers. Groups of teachers in the same content area, same grade, or same department would benefit in working together and can be a "powerful form of teacher learning" (Desimone, 2009, p. 184). Much of the PD being offered is done in isolation with lack of professional learning communities (Little & Housand, 2011).

Other studies have also investigated the relationship of the five features identified by Desimone's (2009) to measures of PD effectiveness. Van Veen, Zwart, and Meirink (2012) reviewed 11 major studies and 34 intervention studies on the effectiveness of PD over the last two decades,[1] finding that that Desimone's five features (particularly content focus) have been adopted with evidence of effectiveness. In addition, Darling-Hammond et al. (2017) expanded

[1] The major 11 works that were reviewed were: Blank and de las Alas (2009); Borko et al., (2010); Desimone, (2009); Hawley and Valli (1999); Kennedy (1998); Knapp (2003); Little (2006); Smith and Gillespie (2007); Timperley, Wilson, Barrar and Fung (2007); Vescio, Ross and Adams (2008); and Yoon, Duncan, Lee, Scarloss and Shapley (2007).

on Desimone's (2009) five-feature framework by adding several elements (e.g., uses models and modeling of effective practice, provides coaching and expert support, and offers opportunities for feedback and reflection). One conclusion that Van Veen et al. (2012) and Desimone and Garet (2015) draw is that the five core features need to be assessed in different contexts in order to show generalizability.

The theory of change summarized in Figure 2.2 shows how these features are expected to affect teachers, their instruction, and their students. There are two theories in teaching and learning that attempt to explain effective PD: (a) how well does PD elicit change in teacher knowledge and instruction, (b) to what extent does the changed method of instruction improve student learning (Wayne, Yoon, Zhu, Cronen, & Garet, 2008). Other research studies have also shown that PD can change teachers' classroom practices (Cohen & Hill, 2000; Correnti, 2007; Fishman et al., 2013; Garet et al., 2001; Jeanpierre, Oberhauser, & Freeman, 2005; Matsumura, Garnier, & Resnick, 2010; Penuel et al., 2007; Roth et al., 2011). A recent study of teachers' participation in effective PD including Desimone's (2009) five features replicated the findings of changes in teacher practices (Fischer et al., 2018). The study also showed that changes in teacher instruction had minimal effects on student achievement (Fischer et al., 2018). Fisher et al. (2018, p. 117) call for advancements in research to inform future teacher PD to identify "sets of instructional practices that relate to increased student learning."

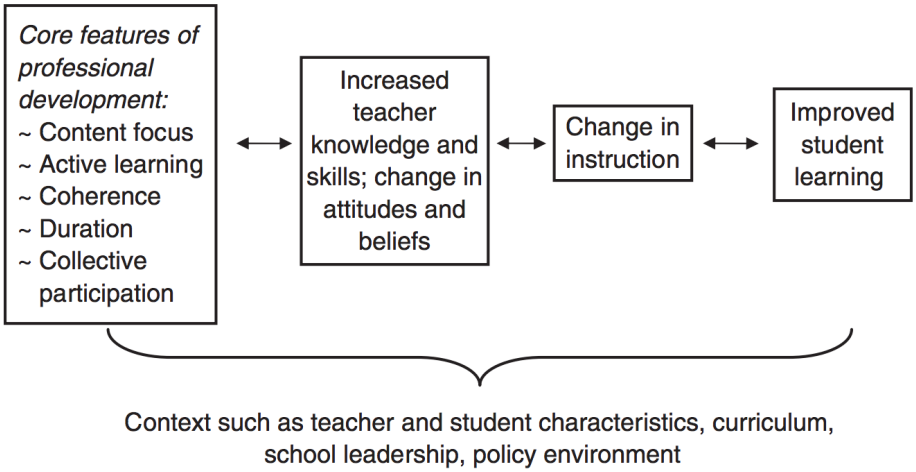

Figure 2.2. Proposed core conceptual framework for studying the effects of PD on teachers and students. From "Improving impact studies of teachers' professional development: Toward better conceptualizations and measures," by L. Desimone, 2009, *Educational Researcher, 38*, p. 185. Copyright 2009 by the American Educational Research Association. Reprinted with permission from the author.

Structure of Online PD Learning. School districts are finding ways to train their teachers with quality PD without the travel expense and without missing classroom instruction time. Teachers also enter online PD programs with various degree of readiness knowledge and beliefs that may stand as barriers throughout the PD experience. Teachers may also have a lack of motivation and unwillingness to participate in an online PD course since it may have been top mandated by supervisors (Dede, 2006).

Online learning is also referred to as distance learning and can allow adult learners to engage in lessons with more flexibility (Dede, 2006). There are teachers who are more comfortable participating in a face-to-face PD program instead of one online and vice versa. Whether teachers participate in a face-to-face or online PD program, the objective for both modes of instruction is effective teacher learning that will in turn help their students learn

concepts more effectively. Fishman et al. (2013) found that the modality of instruction (face-to-face or on-line) did not adversely affect the teachers' learning.

Online PD courses can be offered in several forms. The course can be strictly online or a hybrid (combination of both face-to-face and online). It can be organized into synchronous sessions (facilitator and participants interact in real time), asynchronous sessions (facilitator and participants interact at different times), or a combination of the two. Chen, Chen and Tsai's (2009) study concluded that synchronous discussions in online environments allowed teachers to interact more with one another through online discussions compared to a face-to-face environment (Dede et al., 2009).

Online PD courses can be intimidating to teachers who have no prior experience with online learning. Teachers may feel isolated or discouraged if the course structure is not well organized, there are no clear goals, resources are not readily available, opportunities for collaborative work is not present, and facilitators do not provide necessary feedback (Dede, 2006, Dede et al., 2009).

Supports to Teachers' Online Professional Development Needs

The goal of this section is to provide an overview of the literature that addresses how to improve teachers' online PD learning experience. Although there has been a growing amount of research on the effectiveness and best practices of online teacher PD, it is less common to find literature that focuses particularly on effective practices for online teacher PD in project-based STEM education. The review will examine the research on practices that support participants in an online environment through a situated learning lens.

Following Borko's (2004) conceptual framework for teacher PD, the section below also uses situated learning theory to frame teacher professional learning within the online context.

Building on Bandura's (1986) seminal work on social cognitive theory, Vygotsky's (1978) work on learning through social constructivism, and Piaget's (1977) work on cognitive constructivism, situated learning theory emerged in the late 1980's and early1990's from the work of Jean Lave (1988) and Etienne Wenger (1998) as a model of learning in a community of practice. Situated learning has been defined as learning that occurs as a result of the activity, context, and culture in which it occurs (Lave, 1988; Lave & Wenger, 1991), and conceives learning as "authentic learning experiences" built on the following constructs (Stein, 1998): (a) content, (b) context, (c) community of practice, and (d) participation. Each of these premises within the online environment is considered below.

These situated learning constructs provide a helpful way of organizing the literature on effective online learning. Under content, I review research related to helping online learners acquire the necessary prerequisite knowledge as well as research on best ways for delivering content in an online environment. Under context, I consider research related to the effectiveness of face-to-face versus online PD as well as research on how to structure online PD for optimal learning is considered. Under community, research related to supporting teacher learning opportunities through interactions such as collaboration and practice time with technology in an online setting is examined. Under participation, research related to helping online teachers construct meaning through participatory experiences is considered.

Content

Content is defined by Stein (1998) as experiences and processes learned through activities and application rather than retention and memorization of facts. It is through real-life situations that the learner acquires skills and applies knowledge (Stein, 2001; Stein, Smith, & Silver, 1999). These authentic situations also include acquiring knowledge through interactions,

discussions and reflections with others. Content focused PD is described by Desimone, Nolly and von Frank (2011) as PD that is relevant to the learner because it is content-specific to meet their everyday needs in the classroom. Content is one component in the integrated conceptual model TPACK and is described by Mishra et al. (2006) as the subject matter to be learned and taught. High levels of learning occur when there are active interactions with content to engage learners (Dede, 2006). "Content describes what is learned, context describes the values, beliefs, sociocultural, and environmental cues by which the learner gains and masters content" (Stein, 2001, p. 417).

Teacher prerequisite knowledge. Most research on online learning has little focus on prerequisite knowledge that is expected before teachers begin an online course when learning how to adopt a new curriculum. Prerequisite knowledge is defined in this context as the content and practical knowledge that a teacher should know or be familiar with before starting an online PD program in STEM. Prerequisite knowledge is sometimes assessed with a tool such as an online quiz taken before the start of the online course. For example, before starting the online Design and Modeling course for PLTW, teachers need to pass several quizzes as part of their prerequisite training. The quizzes include questions on content-specific material as well as questions on whether they downloaded a particular software, read a particular article, or viewed a video clip.

Teachers as learners may feel overwhelmed when participating in a first-time online course. They also might not be aware of what technology skills they will need to be successful in navigating in an online environment. Some studies have shown the benefit of administering an online readiness survey to online students and teachers. Student questionnaires predicting achievement success in an online environment have been created in order to assess readiness in

online learning (Bernard & Brauer, 2004; Dray & Miszkiewicz, 2007; Smith, Murphy, & Mahoney, 2003). More recently, an instrument for measuring teacher readiness for online learning, developed by Hung (2016), includes four constructs: (a) self-directed learning, (b) institutional support, (c) communication self-efficacy, and (d) learning-transfer self-efficacy. These measures may help inform PD facilitators of areas of participants' strengths and limitations in order to modify their online instruction in the hope to retain online participants and accommodate their needs.

Preservice teacher training does not sufficiently prepare teachers on how to use technology skills or how to integrate these in their classrooms (Bell, Maeng, & Binns, 2013; Brush, Glazewski & Hew, 2008). Several studies show innovations to increase teachers' prerequisite knowledge and readiness to learn in a contextualized way using Information and Communication Technology (ICT). Using instructional videos as ICT can be one approach to help teachers gain that prerequisite knowledge (Sherin, & van Es, 2009; McGraw, Lynch, Koc, Budak, & Brown, 2007; Semich & Copper, 2018). A video can help deliver content in an engaging manner to learn how to use a technology tool using step-by-step-modeling (Choi & Johnson, 2005). Videos also allow the user to rewind, replay and pause. This is especially helpful for self-pacing in an online course and preventing cognitive overload (Blomberg, Sherin, Renkl, Glogger, & Seidel, 2014; Semich & Copper, 2018). Video can also be used for modeling how to use a specific technology tool or carrying out a process such as creating a Google document (Zhang, Lundeberg, Koehler, Eberhardt, 2011). However, another study by McCarthy and Youens (2005) showed that videos were last on the list among preservice teachers in helping them develop their subject knowledge. This could be because the category was coupled with TV

(i.e. TV/video) and teachers did not have access to quality instructional video resources that were content specific.

In a study by Semich et al. (2018), instructional videos were used as the chosen form of ICT. The study aimed to examine the value of ICT (and specifically instructional videos) for teacher professional development. Out of 70 respondents, 53% strongly agreed that a combination of instructional videos with another mode of instruction was preferred for PD. Participants in the study noted that instructional videos allowed them to revisit material for reinforcement and to brush up on skills and described them as an efficient and engaging way to learn (Semich et al., 2018).

Ponte and Santos (2005) showed that readiness training may be needed for online activities such as reflecting and collaborating, doing open-ended tasks, and discussion. In their qualitative study, Ponte and Santos (2005) focused on a distance PD program in math and were concerned with teachers' reflective collaborative and problem-solving practices. The researchers concluded that there is a need for readiness training in order for teachers to be successful in an online environment, particularly in areas of reflection and collaboration, discussions on forums, and carrying out open-ended tasks (Ponte & Santos, 2005, p.124).

Core training. Teachers participating in PD aimed at adopting a new curriculum are under pressure to return to their classrooms to teach the new content to their students (Vavasseur & MacGregor, 2008). Whether offered face-to-face or online, PD should meet teachers' needs for improving student learning (Dede, 2016; Elliot, 2017). There are multiple studies that suggest best practices in delivering core content in an online environment.

In a mixed-methods study Keil, Rupley, Nichols and Nichols (2016) investigated the experience of 32 teachers who participated in an online STEM PD course called Microgravity

experience (MicroGX) offered through several nationwide school districts and the National Aeronautics and Space Administration (NASA). During the course teachers collaborated on developing experiments that could be conducted in a microgravity environment. Participating teachers were generally satisfied and reported that live chats followed by the structure and content of the PD were the most effective elements, and that the discussion board activities were the least effective element in the PD. Teachers also commented that scheduling of activities across different time zones was inconvenient.

Context

Context is defined by Stein (1998) as the learner's setting and the situations in which the learner masters content. It is through the interaction with the setting, environment, and beliefs that learning occurs (Stein, 2001). Environments that encourage learners to apply technologies in authentic settings are most useful in helping learners master and retain skills (Mishra & Koehler, 2006). Lave (1988) emphasizes that content is best learned situated in context. Fishman et al. (2013) state that what teachers actually learn from PD, in the context of curriculum adoption, is what is more relevant for them in terms of what they teach to their students. Knowles (1984) points out that adults won't engage in learning if they perceive the content irrelevant to their personal or professional settings. PD instruction that is not meaningful to teachers in their content area as well as their context does not lead to changes in their practice because they do not know how students learn that content (Desimone et al., 2011). As Stein (1998, p. 3) puts it: "Context provides the setting for examining experience; community provides the shaping of learning."

Situated learning theory is often mistakenly perceived as a theory that only supports learning and application in the exact same context. Lave (1988) argues that human interaction,

tools, and the activities in practice are most important in acquiring new knowledge. Situated learning embraces learning in authentic environments that provide the learner with the experiences they will need to apply the acquired knowledge in their own setting (Hansman, 2001). Numerous studies (discussed below) address the context of the online learning environment and variations within that context, how learners perceive the context, and how the context can be shaped to provide optimal learning.

Face-to-face versus online PD. Both face-to-face PD and online PD have advantages and disadvantages, and their application depends highly on the PD context. Face-to-face PD may offer a setting for more interpersonal connection and socializing but can be quite costly and may not be accessible. Online PD tends to offer more flexibility as well as accessibility (Russel, et al., 2009). Learning online also differs from learning face-to-face because of "contextual differences in constraints, affordances, and goals (del Valle & Duffy, 2009, p. 130).

There are findings from multiple studies that indicate online PD has outcomes that are just as good or better than face-to-face PD. A study by Fishman et al. (2013) compared the impact of PD modality (face-to-face and online) on teacher practice and student learning. The researchers conducted a randomized experiment with 49 secondary teachers randomly assigned to either an online or face-to-face condition (Fishman et al., 2013). They found that student outcomes improved for this group of teachers that participated in PD; however, the modality of the PD had no significant impact on student performance (Fishman, et al., 2013). A study by Russel et al. (2009) also compared the effects of face-to-face and online PD and found that there were no significant differences in teachers' subject understanding, pedagogical beliefs and instructional practices between the face-to-face group and the online group. They also pointed

out that online teacher participants were more motivated to take another online course while the face-to-face participants were not inclined to take another course.

Structure (Synchronous versus Asynchronous). Online PD appeals to many teachers because it allows them to further their professional growth while meeting their work and family demands (Dash, Magidin, Kramer, O'Dwyer, Masters, & Russell, 2012; Stanford-Bowers, 2008). The difference between synchronous and asynchronous is that synchronous communication occurs in real-time such as in a web conference or in a chat, while asynchronous communication occurs through an online forum or discussion board where there is no live or real time interaction. Both of these e-learning environments have pros and cons and address teacher needs differently in terms of flexibility and time for practice. In a study by del Valle et al. (2007), 59 individuals (73% were teachers) participated in a 25- to 30-hour PD course that was self-paced, problem-centered and entirely asynchronous. There was a concern that participants would have difficulty managing their time; however, this study found that teachers showed effective strategies in achieving course completion.

A combination of synchronous and asynchronous (hybrid) sessions is suggested in online courses to provide flexibility in the busy teacher's schedule and to encourage maximum participation in the courses (Branon & Essex, 2001; Oztok, Zingaro, Brett & Hewitt, 2013). The disadvantages of having only synchronous sessions include a lack of time to reflect and less contributions by participants (Branon et al., 2001; Gilbert & Dabbagh, 2005). Synchronous discussions may involve little "cognitive and metacognitive skills" (Chen et al., 2009, p. 1155) while asynchronous sessions allow for PD participants to read, practice, and contribute on forums with instructors and peers and reflect on content on their own time.

Community

Community of practice is defined as the social setting where participants can learn different points of view from active interactions through reflections and ongoing dialogue (Lave et al., 1991; Stein, 1998). Wilson and Ryder (1996) define community as groups that interact with each other until they meet an end goal. Dede (2006) states that communities of practice are where people construct knowledge from information by testing ideas and receiving feedback. Schlager and Fusco (2003) define communities of practice as a group that engages together to not only learn and complete tasks but to also become better practitioners in their work. Vrasidas and Glass (2007, p. 90) define communities of practice as "sites of mutual learning" where participants can engage in informal talk and more complex problem-solving activities. "Community provides the opportunity for the interaction; participation provides the learner with the meaning of the experience" (Stein, 1998, p. 4). This focus on teachers' community of practice aligns with the collaborative component of Desimone's (2009) framework.

Online community is defined as a "group of people who interact, learn together, build relationships, and who in the process, develop a sense of belonging and mutual commitment" (Wenger, McDermott, & Snyder, 2002, p. 34). In online communities, teachers can apply new ideas almost immediately to their own place of work (Dede et al., 2016), and can then share common issues and success with their online community. Both synchronous and asynchronous sessions are used to build a sense of community through group discussions, online chats and discussions on forums. In a mixed-methods study, Graham (2007) showed an increase in teacher effectiveness among middle school teachers who participated in an online learning community.

Barab and Duffy (2000) describe communities of practice as spaces where there is a legitimate participation to reflect and contribute through dialogue. Online communities can also

strengthen existing face-to-face programs as shown in the mixed-methods study by Vavasseur et al., (2008). They found that the existing technology PD program was strengthened by adding a content-focused online community. Online communities provide a virtual space for the PD facilitator to interact with participants. The interaction between the online PD facilitator and students is important to student's success.

The facilitator in an authentic problem-based program is crucial to the experience of participating teachers (Teräs, 2014). Teachers benefit from a clear protocol for online forum posts and contributions in order to participate effectively. In addition, problem-centered discussions during online PD are more effective when driven by students than if they are driven by the instructor (Rico & Ertmer, 2015; Branon et al., 2001). The facilitator as a coach gives teachers personalized and individualized attention as they work on understanding and implementing new skills, strategies, and knowledge for them and their students (Cox, 2016; Desimone & Pak, 2017; Kretlow & Bartholomew, 2010).

The report by the Bill and Melinda Gates Foundation (2014) identifies coaching and collaboration as two critical components to effective PD. One method of coaching is teachers teaching other teachers as implemented in The National Writing Project's PD sessions (Darling-Hammond et al., 2017). This method of coaching is effective because teachers can relate to other teachers because of shared practices and experiences (Bill & Melinda Gates Foundation, 2014). In addition to coaches supporting teachers in applying newly learned material from PD (Killion, 2012), coaches can also offer follow-up support that is individualized to the teachers' needs (Darling-Hammond et al., 2017). Coaches can also use a collaborative approach when working with teachers. Evidence suggests that collaborative coaching such as in study groups

and facilitated discussions on best practices after PD are valued by teachers (Desimone et al., 2017; Vanderburg & Stephens, 2010).

Participation

Participation is defined as the process through transactions that provides meaning to the learner's experiences by participating in activities such as reflections, presentations and discussions (Stein, 1998). Sing and Khine (2006) state that knowledge is constructed by participating and interacting in a social and cognitive environment. Hrastinksi (2009, p.79) declares that "participation involves action," such as group members talking to one another partaking in a project or modeling a skill. In contrast to working in isolation, active participation is highly encouraged among the members in an online PD environment (Dede et al., 2016). Participation helps members to confirm and construct knowledge as well as to feel part of a team that can provide support for the learning (Hrastinksi, 2009; Lu et al., 2006). "Social participation" as referred by Anderson and Christiansen (2004, p. 24) is also an opportunity for community members to share their expertise and reinforce their professional growth.

Collaborative learning has been established as a mainstay of adult learning as it is for younger learners. A qualitative study by Teräs (2014) sought to understand how to improve teacher quality by improving online collaborative practices in authentic e-learning. A total of 22 teachers completed an online PD program that included three modules that ran for five to six months each. The experiences of seven teachers participating in one of the PD groups were recorded. Learner profiles were created for each teacher describing the collaborative online process. The study's findings showed that online collaboration and facilitation were central components. The researchers emphasized the importance of developing teachers' self-regulation and collaboration skills. A study by Akyol and Garrison (2011) assessed metacognition in online

discussions. One finding showed that graduate students matured metacognitively with time as they posted on the discussion board. A second finding showed that those who provided and received feedback outperformed those who did not. The authors discuss that a community of practice provides the context for metacognitive dialogue and collaborative learning experiences that helps learners construct knowledge.

Teacher collaboration time. Collaboration with other teachers during and after PD addresses teachers needs by allowing them to work on activities and projects together, share practical strategies for implementing new skills and knowledge in the classroom, and reflect on their learning (Bill and Melinda Gates Foundation, 2014) report. High-quality PD includes collaboration among teachers as an effective way to form communities of practice which in turn bring about positive change in teacher practices and student achievement (Darling-Hammond et al., 2017). Evidence from Sandholtz and Ringstagg (2014) showed that there was an increase in teachers' self-efficacy when teachers participated in more collaborative experiences. Another study that sought to find "how practicing teachers' efficacy beliefs and engagement influence their professional learning beliefs" (Durksen, Klassen, & Daniels, 2017, p. 55) showed that collaboration was the most influential on teacher efficacy beliefs for teachers' professional learning.

Collaboration can take place synchronously or asynchronously. Synchronous collaboration occurs with same time interactions among a community of learners, such as through web conferencing. Asynchronous collaboration involves interactions among a community of learners at different times, such as in a discussion forum. Effective collaboration is defined as teachers participating actively in discussions with peers and with the instructor in sharing classroom experiences to learn from one another (Guskey, 2003). During these

discussions, teachers learn from each other and help each other understand complex concepts. However, if the web conferencing tool does not support the number of participating individuals or if the learner has difficulty with their own technology, the online learning experience can be very frustrating.

Teacher practice time with technology. In project-based learning, a problem drives participants to find a solution using problem-solving skills. Teachers need an adequate amount of time (20 or more contact hours) to learn a new technology in order for them to feel confident transferring their knowledge (del Valle et al., 2009; Lim et al., 2013). Darling-Hammond et al. (2017) emphasize that effective PD provides teachers with sufficient time to practice strategies that facilitate change. In a study by Johnson and Fargo (2014), teachers that participated in PD with more opportunities to practice had higher achieving students.

Teachers need an adequate amount of time to practice a new software or piece of equipment in order to gain confidence to teach their students. Studies by Desimone (2009) and Garet et al. (2001) suggest that 20 contact hours of teacher PD is adequate; In the experiments Yoon et al. (2007) reviewed, 49 hours of PD was the average in order to see a significant increase in student achievement.

A pilot study by Gunter and Reeves (2017) evaluated a fully online, instructor-led course named Technology Driven Classrooms: Engaging the iGeneration, which was designed to provide teachers with skills on how to develop and integrate mobile learning tools and content. The qualitative and quantitative findings revealed that teachers were empowered and increased their self-efficacy. This study also showed that content specific and participatory PD leads to positive changes in teacher practices.

Summary of the Factors and Underlying Causes

As this literature review has shown, many factors help to explain why PD is not meeting teachers' needs. Because of their different experiences, teachers have diverse needs that are not always being addressed in how PD is delivered to them. Borko's (2004) model of the PD system, with the teacher is at the center as the learner, structured my analysis of underlying factors affecting the effectiveness of PD. The PD facilitator plays a major role in the teacher's PD experience, both during the experience and after returning to the classroom and school context. Structural conditions of the PD experience, and all the things the teacher brings to the experience, including their self-efficacy, also influence teachers' satisfaction with PD.

This literature review has identified characteristics of effective PD that may help to explain problems related to teachers' dissatisfaction with PD, teacher self-efficacy in technology use, and teacher pedagogical content knowledge related to technology use. Thus, in order to better understand this problem in practice, I will examine the extent to which the problem reflected in the literature exists in my professional context. This following chapter will describe the context of my study, a non-profit organization that trains PD facilitators to teach their proprietary STEM curriculum to teachers.

Chapter 3

Background Information on PLTW

PLTW, founded in 1997, is a non-profit organization that delivers a proprietary project-based STEM curriculum for students in grades K-12. As of 2019, PLTW programs can be found in over 11,000 schools throughout the 50 United States including the District of Columbia and U.S. territories (Project Lead the Way, n.d.-a). PLTW can be found in public, private, and charter schools, as well as in rural, urban and suburban areas.

PLTW offers five curricular programs of study throughout K-12. PLTW Launch is offered for grades K-5; PLTW Gateway is offered for grades 6-8; PLTW Engineering, and Biomedical Science and Computer Science are offered for grades 9-12 (Project Lead the Way, n.d.-b). Table 3.1 lists courses offered in each grade-level division (Project Lead the Way, n.d.-c). PLTW courses are aligned with Common Core State Standards, Next Generation Science Standards, and other national and state standards.

PLTW's PD Training Sites and Modalities

PLTW offers three PD training options (face-to-face, online, blended) for many of their STEM courses. Their face-to-face and blended PD trainings are offered in 17 cities, many at affiliate colleges and universities across the Unites States. Figure 3.1 shows PLTW's PD training hubs (Project Lead the Way, n.d.-d). The PD trainings vary in duration from two days to two weeks depending on the course. PLTW Launch (K-5) classroom teachers attend a two-day face-to-face training while PLTW Launch Lead teachers can choose to attend a two-day face-to-face training or a five-day online training. PLTW Gateway (6-8) teachers attend a three-day or five-day face-to-face training or a 10-week online training. PLTW high school teachers attend a two-week face-to-face training or a 14-week online training (Project Lead the Way, n.d.-c).

PLTW offers their own teacher PD training and development in all of their STEM courses. They use the teach the teacher model where PLTW teachers are initially trained by PLTW curricular developers. These PLTW teachers then become PLTW's PD facilitators.

Figure 3.1. PLTW's training hubs. Reprinted from Project Lead the Way. (n.d.-d). *Our programs.* Retrieved February 6, 2019 from https://www.pltw.org/our-programs/professional-development

Face-to-face courses. The face-to-face PD courses are referred to as Core Training (CT) courses by PLTW. CT courses are intensive training programs that condense a semester-long curriculum into a week or two-week period, sometimes less. The PD courses are usually eight hours daily in duration with collaborative team sessions in the evening and are taught by two PLTW facilitators (co-teachers) that have been trained and have at least one year of experience teaching the STEM unit. During the PD training course, teachers learn concepts in engineering and sophisticated software programs used in the industry. Participants attending the CT complete and submit the same assignments their students must complete and also use the same software required for the course.

Online courses. PLTW's online PD courses were first implemented in 2016 and are referred to as Online Core Training (OCT) courses. OCT courses offer a situated learning experience in which teachers actively teach the course while participating in the PD training. Teachers apply what they learn in their online PD course almost immediately in their classrooms. The time commitment includes 20 hours of synchronous sessions and an additional 30 hours spent on coursework individually. Teachers meet two consecutive hours during synchronous sessions. Although the major concepts taught are the same, the OCT does not follow the same scope and sequence as in the face-to-face PD course. The OCT courses are taught by three PD facilitators. Two of the PD facilitators co-teach the course and the third PD facilitator addresses technology issues as they arise in the online environment during the two hour weekly synchronous sessions. Participants must demonstrate their knowledge and ability to use the specialized software by carrying out many of the same assignments their students must complete in class as part of the curriculum. All assignments are submitted online.

PLTW offers eight different online courses for PLTW STEM teachers. Four of those courses are offered to middle school teachers teaching the following PLTW courses: (a) Design and Modeling, (b) Medical Detectives, (c) App Creators, Computer Science. The other four courses are offered to high school teachers teaching the following PLTW courses: (a) Introduction to Engineering Design, (b) Principles of Biomedical Science, (c) Cyber Security and, (d) Computer Science Essentials (Project Lead the Way, n.d.-c).

Blended learning courses. Blended learning courses are referred to Blended Core Training by PLTW. Blended Core Training courses combine a five-day face-to-face PD over the summer and an OCT during the Fall. In this model teachers also experience the curriculum from the student perspective by completing and submitting many of the same assignments their

students will be carrying out in their classrooms. Participants must complete both the face-to-face and the online PD courses to earn the PLTW certification in the particular course of study.

Table 3.1

PLTW's PD Course Offerings

Curricular Program	Course Name	Modality
Launch (K-5)	K Structure and Function: Exploring Design	Face-to-Face for Classroom Teacher Training
	K Pushes and Pulls	
	K Structure and Function: Human Body	
	K Animals and Algorithms	
	1 Light and Sound	Face-to-Face and Online for Launch Lead Teacher
	1 Light: Observing, Sun, Moon and Stars	
	1 Health and Wellness	
	1 Animated Storytelling	
	2 Materials Science: Properties of Matter	
	2 Materials Science: Form and Function	
	2 Animal Adaptations	
	2 Grids and Games	
	3 Stability and Motion: Science of Flight	
	3 Stability and Motion: Forces and Interactions	
	3 Variation of Traits	
	3 Technology Toolbox	
	4 Energy: Collisions	
	Energy: Conversion	
	4 Input/Output: Computer Systems	
	Input/Output: Human Brain	
	5 Robotics and Automation	
	5 Robotics and Automation: Challenge	
	5 Infection: Detection	
	5 Infection: Modeling and Simulation	
Gateway (6-8)	Design and Modeling (DM)	Face-to-Face and Online
	Automation and Robotics (AR)	Face-to-Face
	Energy and the Environment (EE)	Face-to-Face
	Flight and Space (FS)	Face-to-Face
	Green Architecture (GA)	Face-to-Face
	Magic of Electrons (ME)	Face-to-Face
	Science of Technology (ST)	Face-to-Face
	Medical Detectives (MSD)	Face-to-Face
	APP Creators	Face-to-Face and Online
	Computer Science for Innovators and Makers	Face-to-Face and Online

Engineering (9-12)	Introduction to Engineering Design (IED)	Face-to-Face Online
	Principles of Engineering (POE)	Face-to-Face
	Digital Electronics (DE)	Face-to-Face
	Computer Integrated Manufacturing (CIM)	Face-to-Face
	Aerospace Engineering (AE)	Face-to-Face
	Civil Engineering and Architecture (CAE)	Face-to-Face
	Engineering Design and Development (EDD)	Face-to-Face
	Environmental Sustainability	Face-to-Face
Biomedical Science (9-12)	Principles of Biomedical Science (PBS)	Face-to-Face and Online
	Human Body Systems (HBS)	Face-to-Face
	Medical Interventions (MI)	Face-to-Face
	Biomedical Innovation (BI)	Face-to-Face
Computer Science (9-12)	Computer Science Essentials	Face-to-Face and Online
	Computer Science Principles	Face-to-Face
	Computer Science A	Face-to-Face
	Cybersecurity (SEC)	Blended and Online Only

Note: The Design and Modeling course is one of eight courses offered online as of 2019.

PLTW's Online Design and Modeling Course

After I met with stakeholders from PLTW in April of 2017, they suggested that I focus on their online Design and Modeling course because it is one of their foundation courses that they plan to keep. The Design and Modeling course was one of the first STEM PD courses PLTW offered face-to-face and also in an online environment. The goals of the course are to provide participants with the necessary pedagogical and content knowledge to return to their classrooms confidently and teach the new STEM curriculum to their middle school students. Participants come away with learning the content knowledge of the Design and Modeling course and also how to implement it in their classrooms. The goal for middle school students in this class is to learn the engineering design process, new skills in using specialized software, and how to work collaboratively in groups to solve problems, additionally students learn new skills in using specialized software. The following sections provide more details about the course design.

Prerequisite training. The OCT Design and Modeling course has prerequisite training requirements that need to be completed by the teacher. Each section includes subsections with documents and in some cases activities for teachers to complete and read through. After each section teachers must pass the assessment with a perfect score. If teachers do not pass, then they need to retake the assessment again until they pass with 100%. These requirements must be completed before the core training begins; however, there are exceptions if the teacher is registered and allowed to take the course late. The prerequisite requirements for the Design and Modeling online course includes the following four sections: (a) PLTW: The Experience, (b) Getting Started with Design and Modeling, (c) Getting Started with SketchUp Pro, and (d) Getting Started with GeoGebra. Teachers must pass each of the prerequisite sections with a 100% score and can retake the assessment as many times as it takes to get a perfect score.

Prerequisite training course 1 - PLTW: The experience. This section provides the teacher with an overview of PLTW as an organization and as their PD provider. In order to move on to the next section teachers must open each of the approximately 20 files. After teachers open each file, the word "complete" is posted in green. After teachers have "complete" beside each assignment, they then can proceed to take the short assessment for that section. The assessment includes four multiple choice questions such as "Which of the following best describes the activity- project- and problem-based[2] (APB) instructional approach used in PLTW curriculum?" and "Which of the following characterize PLTW as an organization? Choose all that apply." This section of the prerequisite training provides teachers with several instructional

[2] Project Lead the Way scaffolds assignments within the STEM curriculum using activities, projects and then a real-life problem to solve as their instructional approach.

resources such as video clips and handouts that include rubrics and content specific information relevant to the OCT PD course.

Prerequisite training course 2 - Getting started with Design and Modeling. The second section in the Prerequisite Training is Getting Started with Design and Modeling. This section introduces participants to the course curriculum. This preview includes video clips and handouts on the topics and equipment used in the Design and Modeling course. In addition, this section also provides participants with core training expectations, a supply list, additional software and PLTW's copyright policy. After teachers have completed each assignment, they then can proceed to take the short assessment for that section. The assessment includes questions such as "I have visited the myPLTW Store and am familiar with the equipment and supplies required to teach Design and Modeling"; "I have successfully requested, downloaded, and briefly reviewed the Design and Modeling Standards and Alignment information"; "How long do you have to successfully complete all required PLTW Professional Development prerequisite courses?"

Prerequisite training course 3 - Getting started with SketchUp Pro. The third section in the prerequisite training requirements includes content specific information regarding one of the specialized software participants need to install on their personal computer. This software is required and is needed during the OCT. The following files are available to teachers in this section: (a) SketchUp Pro Installation, (b) SketchUp Pro Assignment, and (c) Instructional Video How-to-Instructions. Google Sketchup is a 3D modeling software that participants use to learn how to design in 3D. After teachers have completed each assignment, they then can proceed to take the short assessment for that section. The assessment includes nine multiple choice questions such as "Have you successfully installed the SketchUp Pro software onto your computer?"; "What are the names of three common Sketchup Inference points?"

Prerequisite training course 4 - Getting started with GeoGebra. The fourth section in the prerequisite training requirements includes content specific information regarding another of the specialized software participants need to install on to their personal computer. The following files are available to teachers in this section: (a) GeoGebra Installation, (b) GeoGebra Assignment, and (c) Instructional Video How-to-Instructions. The computer software GeoGebra is a mathematics software that helps participants learn how to integrate algebra, geometry, spreadsheets, graphing, and statistics to apply engineering concepts. After teachers have completed each assignment, they then can proceed to take the short assessment for that section. The assessment includes nine multiple choice questions such as "Did you successfully download the GeoGebra software?"; "Some tools and terms used in GeoGebra 3D Graphics view are similar to computer-aided design (CAD) applications. If a triangle is created in the Graphics view, what tool would allow you to create a rectangular prism from that triangle in the 3D Graphics view?"

Online core training. The Design and Modeling online course for PLTW STEM teachers offers a situated learning experience where teachers experience the curriculum as a student and complete many of the projects and assignments students are tasked to do. Some of the skills participants learn in the online Design and Modeling PD course include how to draft isometric and orthographic sketches and how to use several software including a three-dimensional CAD 3D models. Rather than learning only course content, the OCT focuses on pedagogical content knowledge to apply concurrently in the classroom. A particular project of the course is to design a therapeutic toy for a child who has cerebral palsy. There are eight OCT learning objectives for participants:

1. Develop confidence in your growing knowledge of course content;

2. Participate in an effective Professional Learning Community (PLC) that provides support and collaborative learning related to teaching the course;
3. Develop confidence in your ability to effectively facilitate student learning of course content;
4. Implement instructional methods that support your role of teacher as facilitator;
5. Reflect on your own instructional techniques, continuous improvement of your professional practice and the resulting student learning;
6. Develop assets you can use with your students in your classroom, such as exemplars, instructional videos, and effective assessment items to measure student learning;
7. As a PLC, develop effective assessment items to measure student learning;
8. Earn PLTW Certification to teach this course (PLTW OCT Syllabus, 2019)

Participants must concurrently teach the PLTW Design and Modeling course in their classroom and participate in the OCT. The Design and Modeling course begins with a preliminary meeting three weeks before the actual core training sessions. Participants are given those three weeks to complete software downloads and read through curricular material to prepare them for the core training. The Design and Modeling OCT cohorts meet weekly for two hours consecutively. Each Design and Modeling online course is 10 meetings long. Attendance at all weekly two-hour online sessions were mandatory. Below is a description of each weekly OCT meeting as of Fall 2019.

Meeting 1: Introduction to Design and Modeling. The first online session is an introduction to the OCT. PD facilitators talk through a PPT presentation about general course navigation. They also discuss strategies on how to be successful in the PLTW online course including the expected time commitments. A course syllabus and expectations are shared and

discussed. A few of the expectations highlighted in the course are that participants must complete every assignment correctly, attend every online session, as well as participate in the community discussions. Additionally, PD facilitators discuss the Web Conferencing tool Zoom and best practices during online meetings. During this session PD facilitators explain Zoom's breakout rooms. The purpose of the first breakout room activity is to discuss a design challenge activity and its corresponding rubric. The assignment to submit includes the completed design challenge activity and a community post.

Meeting 2: Sketching, measuring and feedback. The second week begins with topics such as attendance reminders, office hours, submission times and other housekeeping notes. The purpose of the first breakout room activity is to discuss the process of collaboration, documentation and reflection. Additionally, PD facilitators discuss what good pedagogy looks like in practice. This session also includes a discussion on student assessment including best practices, challenges, related to peer and self-assessment and group work. A second breakout room offers teachers opportunities to practices technical sketching techniques and work collaboratively. The assignment to submit includes sketching and dimensioning activities.

Meeting 3: Measurement and assessment. The third week session includes a discussion on grade revisions, proper form of submitting assignments and facilitators office hours. The focus of this class is on pedagogical content specifically on how to teach sketching and measuring activities. PD facilitators also discuss how to provide effective feedback and the different forms of feedback that participants can use. The breakout room discussions include strategies on how to build exemplars that will help all teachers during their OCT to help better support their students. Additionally, the cohort as a whole determines the impairment

(disability) they want to concentrate on for the toy modification. The assignment to submit includes activities for preliminary planning of a toy design modification using a decision matrix.

Meeting 4: Mechanical dissection. The fourth week begins with PD facilitators reminding teachers of attendance and participation expectations during breakout rooms. The focus of this class is to understand the process of reverse engineering in order to understand how an object or mechanism was made to improve it. Participants work collaboratively in teams to complete an activity and presentation using a decision matrix. The assignment to submit includes a community post, a team presentation, and evidence that GeoGebra Classic and SketchUp Pro software is installed and functioning.

Meeting 5: Mathematical modeling. The fifth week begins with teams presenting their project toy design modifications to the cohort. The focus of this class is to expose participants to GeoGebra as a mathematical modeling tool to represent and analyze data. Participants submit their own mathematical model.

Meeting 6: Take modeling to another dimension. The sixth week begins with a breakout room collaborative work time and discussion using the computer algebraic system GeoGebra. In particular, participants discuss ways to show students the math behind 3D modeling and how it is used in the real world. Additionally, PD facilitators model two techniques of solid modeling to develop 3D models. They demonstrate additive and subtractive methods using Google Sketchup. The assignment to submit includes sketches of the puzzle cube parts that participants design using Google Sketchup.

Meeting 7: The puzzle cube. The eighth week begins with addressing the cohort's questions or misconceptions. The focus of this class is to test and assess the effectiveness of a prototype using the mathematical model created by GeoGebra.

Meeting 8: The design challenge. During this class PD facilitators introduce the unit problem and guidelines that participants must solve collaboratively in teams. Participants work in teams and define what toy they will design and build for a child who has physical, sensory, or cognitive challenges. Participants begin working on a community post and their decision matrix for the Toy Design Challenge.

Meeting 9: The design challenge. During the ninth-class participants continue working on creating their toy designs with the specific content knowledge they have learned during the previous training sessions. Participants complete and submit a community post and their decision matrix for the Toy Design Challenge.

Meeting 10: Effective feedback and presentations. During the tenth and last class participants work collaboratively on putting together their presentation on their toy design. Participants share their screens and presented their toy design. As part of their last class participants are asked to complete an end-of-course (e.g. satisfaction) survey.

PLTW's PD Facilitators

PD facilitators are described by PLTW in the confidential 2019 PLTW Master Teacher Agreement as "instructors appointed by PLTW to facilitate training events that fit within PLTW's three phase PD model (Prerequisite, Core, and Ongoing Training). Master Teachers[3] possess a rich understanding of PLTW and its mission, the knowledge, skills, and habits of mind required to successfully instruct PLTW curricular offerings and can apply principles of adult learning to the development and delivery of training. Master Teachers act as instructional role models, ambassadors of PLTW's mission, and mentors to teachers in PLTW's network."

[3] PLTW's facilitators are referred to as Master Teachers in the organization.

PLTW outlines the roles, responsibilities and duties that PD facilitators agree to uphold. PLTW's PD facilitators are required to participate in PLTW's ongoing PD trainings and remain current with curriculum updates and revisions. PD facilitators are also asked to be an engaged member of the PLTW Professional Learning Community. Additionally, constructive feedback is asked of PD facilitators in order to improve training programs.

In order to be eligible to apply to become a PLTW Master Teacher, teachers must meet the following requirements: (a) teacher must be a PLTW trained teacher (b) teacher must themselves have taught the unit in its entirety (c) teacher must be working in a school that has adopted the PLTW curriculum. Only teachers meeting these requirements can apply. There are three application components that teachers need to submit. These are a resume, a recommendation form, and three short essays on the following topics: knowledge and awareness of adult learning, APB instructional approach, and their own story as a PLTW educator. In addition to these requirements, teachers interested in becoming an online Master Teacher must also participate in a six weeklong (six sessions) training, specific to online teaching.

PLTW Values Teacher Feedback for Continuous Improvement

PLTW has continuously improved its STEM curriculum with the help from teacher feedback. Participants are offered many opportunities to voice their recommendations and commendations. Participants are asked to complete a satisfaction survey after each of the weekly online PD sessions, after the end of the OCT and when they are teaching the curriculum in their classrooms. The organization takes teacher feedback seriously and depends on it for continuous program improvement.

Chapter 4

Methodology

The purpose of this study was to describe teachers' experiences of PLTW's online STEM Design and Modeling course. This study sought to contribute to our understanding of how teachers received the PD provided to them and to identify suggestions about how the PD could be improved to have more influence on teacher practice. The following research questions guided the dissertation study:

RQ1: What are teachers' perceptions of an online STEM professional development course?

RQ2: What components of an online professional development course function as supports and barriers for teachers in acquiring pedagogical and content knowledge?

RQ3: How do teachers describe their confidence in implementing a STEM curriculum after an online professional development course?

The following sections describe the research design, study participants, data collection procedures and measures, and data analysis methods.

Research Design

This exploratory descriptive study employs a sequential mixed methods design, in which qualitative data were collected after archival quantitative survey data and the data were interpreted separately (Creswell & Plano Clark, 2011; Fetters, Curry & Creswell, 2013). A mixed-methods approach is important in this study to provide a more comprehensive understanding of teachers' PD experiences. The pragmatic world view philosophy helps shape this mixed methods study because the practical solutions and meaning derived from the study

can be transferable (Shannon-Baker, 2016) to other online PD courses that emphasize project-based learning in STEM.

Participants

In August of 2019, all 217 teachers that participated in the 2018 online course training and 133 teachers from the Fall 2019 online course were invited to participate in the study through an email letter (Appendix A) describing the study. The letter had a direct link to the letter of informed consent form (Appendix B) for the individual interview. After participants consented to participate in the study, they were asked to complete a brief questionnaire (Appendix C). The purpose of the screening questionnaire was to select a diverse number of participants in case there were over 30 participants that agreed to be interviewed. The rationale for including participants from both 2018 and 2019 was to describe differences in their perceptions of the online course training.

A total of 26 completed the preliminary screening survey, and 22 consented to be in the study. All 22 teachers who consented to participate in the study were invited to participate in interviews, but only 18 were interviewed. Table 4.1 summarizes demographic characteristics of the teachers participating in the study (based on data from the preliminary screening survey).

Table 4.1

Demographic Characteristics of Teacher Interview Respondents

Characteristic	*n*	%
Sex		
Male	4	22.2
Female	14	77.8
Race/Ethnicity		
Hispanic/Latino	1	5.6
White/Caucasian (non-Hispanic)	17	94.4
Time Zone		
Eastern	8	44.4
Central	6	33.3

Mountain	3	16.7
Pacific	1	5.6
Years of Teaching Experience		
3-5	4	22.3
6-10	2	11.1
11-15	3	16.7
16-20	3	16.7
>20	6	33.4
Years of teaching a PLTW Course (if any)		
<1	6	33.3
1-2	7	55.6
3-5	1	5.6
6-10	1	5.6
Previous experience with Online Learning		
Yes	12	66.7
No	6	33.3
Previous experience in other PLTW trainings	12	66.7
Yes	6	33.3
No		
School Area/Setting		
Rural	2	11.1
Urban/City Area	7	38.9
Suburban	9	50
Certification Area		
Grades 1-8	2	11.1
Science	6	33.3
Math	2	11.1
Career and Technical Education	2	11.1
Computer Science	1	5.6
English Language Arts	1	5.6
Elementary Education	4	22.2
Highest degree received		
Bachelor's degree	5	22.2
Master's degree	12	66.7
Doctoral degree	1	5.6

Note: N = 18 responses from participating teachers interviewed.

A total of 21 PD facilitators who had taught the 2018 and/or 2019 online Design and Modeling STEM course were invited to participate in the study through an email letter (Appendix D) describing the study. A total of six PD facilitators consented to be in the study and all six participated in the individual interviews. All PD facilitators had more than six years

of teaching experience and all had at least one year of teaching the online Design and Modeling course.

Archival survey data from a total of 216[4] participants in the online Design and Modeling course during 2018 and 2019 were also used for this study, although these individuals were not directly recruited as study participants. Archival records did not include demographic characteristics of these survey respondents.

Data Collection and Measures

Using measures from several different data collection methods (e.g. open-ended responses from satisfaction survey, ratings from satisfaction survey, interviews, and online classroom observations) constitutes a triangulation approach to validate findings (Creswell, 2014). The data sources for this study included: (a) surveys, (b) semistructured interviews, online classroom observations, and (d) a researcher's journal.

End-of-course satisfaction survey (archival records). Archival data used in analysis were collected by PLTW from mid-September, 2018 through late September, 2019 after 11 different cohort sessions of the online Design and Modeling course. PLTW sent links to participants' email address asking them to complete the survey online. Comparable survey data from a total of 126 teachers participating in 11 different cohorts[5] of the PLTW online Design and Modeling Course during 2018 and 2019 were provided by PLTW for analysis. Participants rated the course on several different dimensions using a five-point Likert-type scale (1 = *poor* to 5 =

[4] This number represents a subset of the total number of respondents who had data on comparable measures for both 2018 and 2019.

[5] PLTW uses the term "cohort" to designate participants taught together over the ten week in separate section of the online training course.

excellent), and two open-ended items that allowed participants to provide additional information on negative ratings and to voice their commendations and recommendations. Teachers responded to questions related to their satisfaction with the prerequisite and core training, perception of their gains in content and pedagogical knowledge, and confidence in implementing the STEM curriculum. See Appendix E for the full list of survey questions. As described more fully in the Data Analysis section below, I created scales from survey items to measure overall satisfaction with the course and level of confidence for teaching the Design and Modeling course to their students after the training.

Semistructured interviews. PLTW emailed all 2018 and 2019 teachers and facilitators explaining that PLTW granted the researcher permission to contact them about an interview. All teachers and facilitators willing to participate were interviewed over a 13-week period starting October 8, 2019 and ending in January 16, 2020. Participants were assured anonymity and confidentiality. Interviews were conducted over the phone or web conference tool called Zoom and were audio recorded (with participant consent) for ease of future analysis.

Teacher interviews. Semistructured interviews solicited teachers' reactions regarding their overall satisfaction with the PD program, confidence for using the technology, and their acquisition of pedagogical content knowledge related to technology use. There were 17 predetermined interview questions and additional probes during the interview process depending on participants' responses. Interview questions focused on participant experiences with different aspects of the online course and participant confidence in teaching the new curriculum after completing the course. The full list of interview questions can be found in Appendix F.

PD facilitator interviews. The semistructured interview of facilitators included 10 questions related to their perceptions of supports and barriers in the online PD for teachers in

acquiring pedagogical content knowledge, with additional probe questions added during the interview process depending on the participants' responses. Interview questions focused on such issues as facilitator perceptions about resources for teaching the course and additional resources or changes to the course that could contribute to the participants' learning. The full list of interview questions can be found in Appendix G.

Online classroom observations. Field note data were collected during 16 synchronous sessions for the 2019 Fall online Design and Modeling course cohorts from October 1 to December 18 using an online classroom observation instrument (Appendix H). Screenshots were taken of content related instruction and described in detail to explain the relevance to the online course (e.g., course design, pedagogical content knowledge, and confidence). An online classroom observation instrument[6] was developed in order to describe the classroom environment. The instrument focused on the amount of time devoted to the following components, as well as observed strengths and weaknesses related to each component: content instruction, instructional pedagogy, practice time with new content/technology, collaboration with facilitator or other teachers, down time due to issues with technology, and down time due to other issues.

Researcher's journal. A researcher's journal was created over the duration of the study to record field notes and to write down observations during class time and notes during meetings with stakeholders. The researcher's journal helped to maintain orderly records of participants' interactions and the researcher's interactions with stakeholders as well. Journal entries were both digitally recorded using Microsoft Word and handwritten in a composition notebook.

[6] The student researcher developed the classroom observation instrument after observing PLTW's online classes in the Fall of 2017, and shared it with PLTW for feedback. Observations were conducted with PLTW's permission.

Data Analysis Process

A quantitative analysis was done of survey data using SPSS. Descriptive statistics were used to compare mean responses of respondents in the two different years on each of the measures. Scale measures using multiple survey items were constructed to measure overall participant satisfaction, satisfaction with course emphasis on content and pedagogy, and confidence for teaching the PLTW curricula.

The thematic data analysis approach described by Braun and Clarke (2006) was used to analyze interview responses, observations, open ended questions and researcher's journal. Interviews were transcribed using a transcription software called Happy Scribe to create text for qualitative analysis, which sought to identify emerging themes (Creswell et al., 2011). Transcriptions were checked for accuracy. Comments were then coded by major themes and summarized as described above. I first familiarized myself with the data by reading it carefully multiple times to identify recurrent themes, at which point I conducted a word search to identify the frequency of the recurring themes and color-coded each to develop initial codes. I then reread the data and created a code book including the recurring themes, examples of each and how each theme is defined and its connection to the research questions. Lastly, I created a data analysis chart to report the data results (Braun et al., 2006). To analyze the qualitative data, open ended survey questions and comments provided by respondents were read several times to identify emerging themes (Creswell et al., 2011). Comments were then coded by major themes, and summarized, noting frequency with which different themes appear and using quotes of typical comments within categories to illustrate findings.

Data integration. In this convergent mixed methods study, it is not enough to analyze the data separately from each another. The process of data integration and interpretation is a

critical part of this design (Creswell et al., 2011). In this study, quantitative and qualitative data were integrated to strengthen the validity of the findings (Fetters et al., 2013). Integration occurred through "connecting" or explaining the qualitative and quantitative data through sampling (Fetters et al., 2013, p. 2139). For example, in this study a subgroup of the survey participants was formed to conduct interviews. This provided qualitative data to support the quantitative findings.

Triangulation. Triangulation of data is described by O'Leary (2017) as using multiple sources and multiple approaches to collect data to confirm the authenticity of the sources and is important in testing the consistency of the findings and provide a more comprehensive explanation of the phenomenon observed (Creswell & Plano-Clark, 2011; Martinson & Obrien, 2015; O'Leary, 2017). In this study, data triangulation and methodological triangulation using member checking was used. To triangulate data I aligned interview, open-ended, and quantitative survey questions to the research questions. Member checking was carried out by sharing the research questions with PLTW's PD team, and interview transcripts and reported findings with participants interviewed so they could review the content and intent thereof (Creswell & Plano-Clark, 2011; O'Leary, 2017).

Researcher Positionality

It is critical for researchers to share their biases and be transparent about their intent in a study (Onwuegbuzie & Leech, 2007). My educational background and experiences in science and technology education may influence my interpretation of teachers' PD experience in program satisfaction and implementation, confidence and acquiring pedagogical content knowledge. There are both benefits and drawbacks when someone studies a topic with which they have considerable personal experience. I have a deep understanding of the PLTW PD

experience from the perspective of both participant and facilitator, which is extremely valuable, but I also have unknown biases that could influence my interpretations.

I began teaching Science in one of Boston's inner-city public middle schools in Jamaica Plain. I then taught Montessori students ages three to six for three years in a Massachusetts suburb. For 13 years, I worked at a private independent middle school in suburban Miami and held various positions including that of teacher. I participated in my first face-to-face PLTW training at Rochester Institute of Technology in upstate New York in 2006. In the same year I was trained in PLTW's Design and Modeling, Magic of Electrons, Science of Technology, and Automation and Robotics. I then earned my certification for their specialization units Energy and the Environment, Flight and Space, Medical Detectives and Introduction to Computer Science. I have taught all of these units as a classroom teacher and as a Master Teacher for PLTW. Additionally, I trained in Launch, (PLTW's K-5 STEM curriculum) and was a lead teacher as well. I also chaired a 12-member science and engineering department that adopted the PLTW K-8 curriculum and ensured teachers had all of the necessary resources to carry out the PLTW curriculum successfully.

As a trained PLTW teacher and PD facilitator, I found myself in common territory with the organization's language of instruction and processes. In order to minimize the personal biases that could result from this, I involved stakeholders throughout the process of developing my study to ensure it was adequately designed to meet their needs. Research questions were carefully aligned with the constructs found in PLTW's satisfaction survey (see Summary Matrix Appendix I). Interview questions were also closely aligned to each of the research questions. To avoid personal bias, I took detailed notes and read interview transcripts multiple times in order to code themes according to those predetermined in the codebook.

Chapter 5

Findings

This chapter reports findings from this study of perceptions of the PLTW online Design and Modeling course. Findings are arranged by the study's three research questions, which focused on: (a) teachers' perceptions of an online STEM PD course, (b) how the components of the course function as supports and barriers in acquiring pedagogical and content and knowledge, and (c) teachers' confidence in returning to their classrooms and implementing a STEM curriculum. Each section includes findings from quantitative analyses of archival survey data and analyses of qualitative data, followed by an integrated summary.

RQ1: What are Teachers' Perceptions of an Online STEM PD Course?

The first research question addressed teachers' overall perceptions of the online STEM PD course. To answer this question, analyses were conducted using descriptive statistics from the end-of-course satisfaction surveys and thematic analysis of interviews and open-ended responses from the end-of-course satisfaction survey data.

Quantitative Findings

Table 5.1 summarizes end-of-course survey responses from teachers who participated in the Design and Modeling OCT in 2018 and 2019. Responses to these survey items were highly correlated, with the five items forming a highly reliable scale (Cronbach's alpha = .943). Average scores ranged from $M = 4.10$ to $M = 4.31$ (on the 5-point scale that ranged from *poor* to *excellent*) across the five items. Teachers highly rated the opportunities, experiences, and assignments that were provided to them with the guidance of their facilitator. The lowest rated item by teachers was the pace at which material was covered ($M = 4.10$, $SD = 1.01$).

On a separate survey question, 88% of participants selected seven or higher (on a scale from 0 to 10) for how likely they would be to recommend the OCT experience to another teacher or administrator ($M = 8.48$, $SD = 1.94$).

Table 5.1

Overall Course Satisfaction Questions used from End-of-Course Satisfaction Survey for Analysis

	Item	*n*	*M*	*SD*	*% Excellent (rated 5 on 5-point scale)*
How would you rate online core training on:					
Q1	Providing prerequisite materials that strengthened knowledge skills and mindsets needed to successfully engage in Core Training.	123	4.14	1.05	48
Q2	The pace at which material was covered.	122	4.10	1.02	43
Q3	Providing opportunities to experience conceptually challenging concepts from the course curriculum with the guidance of Master Teachers.	122	4.31	.988	58
Q5	Helping me understand how the knowledge and skills students learn in PLTW develop career connections.	121	4.13	1.05	48
Q12	Providing assignments outside of synchronous online sessions that consisted of exercises of an appropriate length and difficulty.	121	4.25	1.08	56

Note. Questions 1, 2, 3, 5, and 12 were used to construct a course evaluation scale.

There was no significant change over time (from 2018 to 2019) in teachers' overall ratings of the course. There was, however, notable variation in average participant satisfaction among the various cohorts (enrolled in different sections of the course delivered at different times) that appeared to be related to particular sections or instructors. Analysis of variance

(ANOVA) results indicated significant differences (p = .007) among sections. It was also notable that ratings tended to be lower in cohorts with fewer survey respondents. It is possible that only those with more negative views than average responded to the survey in those sections, but no definitive conclusion about this is possible from the data available. Table 5.2 summarizes the variation in the overall satisfaction scores across cohorts (organized from highest to lowest rather than in chronological order of course cohort delivery). Overall teachers were highly satisfied with their online STEM PD course (M = 4.19, SD = .932). Appendix J reports scores on each survey item by cohort.

Table 5.2

Descriptive Statistics by Cohort for Course Evaluation Scale

Cohort	Overall Course Evaluation (Q's 1, 2, 3, 5, 12)		
	n	*M*	*SD*
A	10	4.70	.591
B	7	4.60	.416
C	19	4.46	.690
D	21	4.29	.728
E	18	4.26	.863
F	12	4.17	.877
G	20	4.03	1.13
H	2	3.75	1.06
I	7	3.69	1.12
J	4	3.45	1.23
K	3	2.40	1.40
Total	123	4.19	.932

Note. PLTW considers 5.00 to be the standard for excellence.

Qualitative Findings

There were several themes that emerged from analyses of the survey's open-ended responses[7] and the semistructured interviews. In general, these themes can be characterized as strengths and challenges or frustrations associated with particular dimensions of the course. The following section describes these themes and provides illustrative examples within each of the following course dimensions: course structure and pacing, instruction, collaborative learning among participants, and instructional technology.

Structure and Pacing

General issues with structure and pacing. Supports and challenges encountered by teachers in terms of structure and pacing were facilitator dependent. Fifteen of the teachers interviewed felt the structure and pace of the course supported their learning. They felt the pace was "really easy to follow," and "manageable" thanks to the support they received from the course facilitator. The majority of the teachers made positive comments, described the course as "well structured," and continued to explain that the structure and pace of the course allowed for "every opportunity to enhance or supplement the learning experience with the Master teacher or students in the cohort." Some challenges teachers voiced centered on allocation of course time (e.g., too much time on pedagogical topics such the "feedback assignment" and not enough time on dimensioning or instructional software related topics). Three of the teachers felt the pace and structure of their first two classes were "disjointed," and "disorganized." They further voiced

[7] Two open-ended questions from the PLTW survey provided insight into participants' ratings. Open-ended survey questions asked teachers to provide additional information about their rating on their overall course satisfaction (21 responses from 2018 and 28 responses from 2019) and to provide additional information on any item that was rated *fair* or *poor* (5 responses from 2018 and 11 responses from 2019).

their opinion that this was due to a lack of planning and coordination on the facilitators' part. (Each class had three facilitators working together.) One teacher described her experience as a "patchwork quilt approach" observing that "instructors were very disjointed." Another frustration mentioned occurred when the facilitator responsible for overseeing technical issues and grouping teachers into breakout rooms did not plan ahead, which led to mismatched groups and also led to confusion.

Issues with synchronous structure. Teachers felt that meeting once a week for two hours was onerous but necessary to cover all of the material. Most teachers felt that the weekly two-hour synchronous sessions were productive, and they "liked the live contact" and meeting weekly while they taught. Teachers felt that the two-hour sessions allowed time for sharing ideas and sharing feedback on assignments and classroom experiences. Teachers' biggest overall complaint was that they had a lot to manage in addition to learning and adopting the new STEM curriculum. The majority of teachers thought the online course would allow them extra flexibility with their professional responsibilities but did not realize the large amount of time commitment needed to complete all of the group work and homework assignments.

Perceived time commitment. Teachers who had a negative experience with the PD course had a misconception of the time commitment necessary to complete the work. Out of 65 responses from the open-ended questions, 22 teachers felt this way. As one respondent said, "the suggested time commitment versus the actual time commitment was way off." Teachers were frustrated with the level of time commitment needed to complete homework assignments, and group projects. This was especially challenging for teachers because they needed to "balance school, family and the course." Several teachers pointed out that online learning was "tough" and this "option requires more discipline."

Instruction

Clarity of facilitators' instruction. Teachers felt course assignments were relevant but that there were inconsistencies with the grading, quality and timeliness of feedback and clarity of instructions. Teachers also felt that the quality of instruction depended on the facilitator and the dynamic of the three facilitators in the cohort. Some facilitators worked more closely together and had a more organized and systematic method to their teaching that showed pre-planning. Other facilitators, on the other hand, lacked organization and had weaker pedagogical strategies and tended to read lengthy assignment directions to participants instead of offering demonstrations or practice time. One teacher stated that "if you are having to spend eight hours looking at a YouTube videos because the lesson was unclear, instruction needs to improve." Teachers also felt that there should be less focus on pedagogical instruction and more emphasis on the content that needed to be learned to teach their students. They also shared frustrations about not receiving graded homework assignments in a timely manner and sometimes without quality, and actionable feedback. Some teachers felt overwhelmed when facilitators changed the requirements and added more work as part of their deliverables. Teachers also expressed frustrations with the lack of clarity of instructions before breakout sessions.

Facilitator responsiveness. Teachers who had a positive experience with the responsiveness of their facilitators had an overall higher satisfaction with the PD course. The majority of the teachers felt their PD facilitators were highly responsive. They described their facilitators as "helpful and knowledgeable." Several teachers reiterated that facilitators made themselves available before and after class time to answer questions. One teacher said about their facilitators that "they would stop what they had planned to teach if students were having trouble." There were however some challenges that teachers expressed due to poor facilitator

responsiveness. A few teachers were frustrated that their questions were not answered in the chat box during class time and that breakout sessions were not monitored. One teacher said that "they need to check what people are doing in the breakout rooms" another teacher said that "comments in the chat box are sometimes overlooked and not answered."

Collaborative Learning Among Participants

Collaboration among participating teachers during the course allowed for an exchange of ideas but was limited by issues in group structure and dynamics. Teachers felt frustrated when their facilitators grouped them without taking into consideration their time zone or other commonalities such as if they worked in the same school district. They found it difficult to collaborate on assignments and projects with teachers that were in different time zones. Teachers also expressed a lack of collaboration during breakout sessions because they were often unclear of what needed to be discussed. Teachers felt they were often asked to collaborate in breakout rooms without having a clear focus or access to the instructions and being asked to "go discuss." As one teacher said, many of my breakout sessions with other class members were spent just trying to figure what was even due." One teacher said that "I learned to take a screenshot of the instructions before going into the breakout room." They felt there was a lack of clarity on what needed to be accomplished during the breakout sessions. These issues were also facilitator dependent as there were teachers who felt that the collaboration during breakout rooms was smooth and said that "breakout groups, collaborating with the other teachers and really hearing what other teachers who are in different places from around the country were doing as well as learning the success and challenges they are facing were helpful."

Instructional Technology

Ease using Zoom. Teachers found that using video conferencing was conducive to adopting and learning a STEM curriculum. The majority of the interview participants (14 out of 18) felt that the video conferencing tool Zoom was easy to use and user friendly and described the tool as "fabulous or great." Teachers that had connectivity issues (4 out of 18) were due to poor residential internet service, district firewall restrictions on their work computers or lack of experience with technology. A couple of teachers did not have the same Zoom features visible on their personal computers and one teacher felt intimidated in using the screen share feature. One teacher expressed their gratitude in receiving headsets from PLTW in order to stay engaged during the online classes.

Frustrations with learning management system. Both teachers and facilitators expressed frustrations in the method of receiving and submitting assignments and feedback on the Learning Management System (LMS) NetExam. They felt that "the platform that PLTW used in terms of their Word files is a very arcane system for sharing files and turning in your work." Although Google Drive is not promoted by the organization, most of the facilitators use Google Drive with teachers to share resources. Facilitators also used Google Drive to accept and comment on assignments. Teachers felt that Google Drive was much more user friendly when receiving and submitting assignments. This produced more work for teachers since their facilitators were using Google Drive to give feedback on assignments, but they then had to upload their final assignments to the LMS. Additionally, teachers expressed frustration with the complexity of the LMS for student use. This caused teachers to take it upon themselves to download all of the assignments and upload them onto Google Drive to share with their students.

Summary

Research Question 1 sought to understand teachers' perceptions of an online STEM PD course. Collectively, teachers perceived the STEM PD course as a positive experience overall in both the quantitative and qualitative data. Among interview respondents, six out of eight from the 2018 course and nine out of ten from the 2019 course reported to have a positive experience. Among the open-ended questions, 20 out of 21 responses from the 2018 course and 19 out of 28 responses from the 2019 course had a positive experience overall (two responses were neutral). The data showed teachers' overall perception of the course was overwhelmingly colored by their PD facilitator. Teachers that had facilitators who provided more direct instruction and guided hands-on practice time with the more complex content felt more satisfied with the course. This is probably because they were able to increase their confidence by gaining experience with more difficult skills such as technical drafting and designing with 3D modeling software. Overall teachers across cohorts voiced frustrations about the cumbersome procedures required to download and upload assignments. Most teachers preferred to use Google Docs to complete assignments and share them with their facilitators before uploading these to the LMS. As is evident from both the quantitative and qualitative data, both support the idea that the perception of the experience of the course was largely dependent on the effectiveness of their facilitators. Teachers offered meaningful feedback on how they perceived the STEM course.

RQ2: What Components of an Online Professional Development Course Function as Supports and Barriers for Teachers in Acquiring Pedagogical and Content Knowledge?

The second research question addressed what components of an online PD course function as supports and barriers to teachers in acquiring pedagogical and content knowledge. To answer this question thematic analysis was conducted on open-ended responses from the end-

of-course satisfaction survey, interviews from both teachers and facilitators, online classroom observations, and the researcher's journal. Descriptive analysis of survey responses provided context about participants' general satisfaction with the course focus on content and pedagogy. In addition, descriptive analysis of time allocation observed in class sessions indicated variation in instruction emphasis on content and pedagogy.

Quantitative Findings

Survey findings. End-of-course survey responses for questions related to pedagogical and content knowledge from teachers who participated in the online Design and Modeling Core Training in 2019 are summarized in Table 5.3. Responses to these survey items were highly correlated, with two items forming a reliable scale (Cronbach's alpha = .894). But participating teachers felt that there was more adequate focus on course content ($M = 4.22$, $SD = .922$) than pedagogy ($M = 4.03$, $SD = 1.15$).[8]

Table 5.3

Pedagogical and Content Knowledge Questions used from End-of-Course Satisfaction Survey for Analysis

	Item	*n*	*M*	*SD*	*% Excellent (rated 5 on 5-point scale)*
How would you rate online core training on:					
Q9	Providing an adequate focus on course content.	60	4.22*	.922	50
Q10	Providing an adequate focus on pedagogy.	61	4.03*	1.15	46

Note. Questions 9 and 10 were used to construct a pedagogical content knowledge scale. *Asked only in 2019.

[8] Unfortunately, the 2018 survey question asked about both content and pedagogy together and data from those respondents could not be used in analysis. In 2019 the survey question was split into two survey items used in the analysis, but the number of respondents was only about half the size of the group in the analysis for Research Question 1.

There was notable variation in average participant satisfaction with the course's focus on content and pedagogy among the various cohorts that appeared to be related to particular sections or instructors. ANOVA results indicated significant differences (p = .042) among sections. As in Table 5.2, ratings tended to be lower in cohorts with fewer survey respondents. To reiterate, it is possible that only those with more negative views than average responded to the survey in those sections, but no definitive conclusion about this is possible from the data available. Table 5.4 summarizes the variation in the satisfaction of pedagogical and content knowledge scores across sections (organized from highest to lowest rather than in chronological order of course cohort delivery).

Table 5.4

Descriptive Statistics by Cohort for Pedagogical and Content Knowledge Scale

Cohort	Pedagogical and Content Knowledge (Q's 9, 10)		
	n	*M*	*SD*
D	21	4.31	.750
G	20	4.30	.938
F	11	4.14	1.05
H	2	4.00	1.41
J	4	3.50	1.08
K	3	2.50	1.32
Total	61	4.12	.990

Note. PLTW considers 5.00 to be the standard for excellence.

Online class observations. Table 5.5 summarizes findings from the researcher's observations of 16 different synchronous class sessions from six different cohort groups of participants in Fall 2019. The table displays the number of minutes during each two-hour session devoted to different components. For the most part facilitators tried to divide the class time to offer teachers both direct instruction of new skills related to the new content (such as

demonstrating how to create a multiview drawing on isometric paper) and instructional pedagogy, which included tips and personal insight on how to teach a particular lesson. My observations included the time that facilitators spent reading assignment instructions to teachers as part of instructional pedagogy. On average, more class time was spent on discussion (32%) and instructional pedagogy (31%) than on practice time (20%) or direct instruction of content (9%). But there was particularly wide variation across the sessions in the amount of class time spent on practice time with new skills (0 to 78%), discussion (0 to 70%), and instructional pedagogy (12% to 82%). There was somewhat less variation in time spent on direct content instruction (0% to 44%). The table also summarizes time spent on participants' discussions with the facilitator or other participants, as well as down time due to technology other issues. Observations showed that in general, there was little time lost during class due to technology problems. This occurred in only 3 of the 16 classes observed, and took as much as 15 minutes in just one of the classes (5-6 minutes in the other two). More classrooms had down time due to non-technology related issues (5 of 16) but on average the time lost was less than 6 minutes.

Table 5.5

Amount of Class Time Allocated to Each Component

Cohort Observed	Session #	Direct Instruction of New Skills (Content)	Instructional Pedagogy	Practice Time with New Skills	Discussion with Facilitators or other Teachers	Down Time Due to Issues with Technology	Down Time not Due to Technological Issues	Total Time by Cohort
1	7	0	55	0	33	15	0	110
2	7	0	55	0	60	5	0	127
3	5	4	46	45	15	0	0	115
3	6	56	19	30	15	0	0	126
3	9	0	30	0	90	0	0	129
3	10	0	20	15	85	0	0	130
4	1	0	99	5	0	6	10	121
4	4	0	40	60	15	0	5	124
4	8	20	70	15	15	0	0	128
4	10	0	20	15	90	0	5	140
5	3	27	33	25	32	0	3	123
5	9	30	30	45	15	0	0	129
5	10	0	15	15	90	0	0	130
6	6	42	40	30	8	0	0	126
6	9	0	20	100	0	0	0	129
6	10	0	15	10	90	0	5	130
Total Time by Component		179	607	410	653	26	28	

Note. Observation time is representative of different cohorts and during different class sessions. Time is represented in minutes. Sixteen sessions from six cohorts were observed. Online observations were for the full duration of the class (two hours in length). Total time for observed classes was not exactly 120 minutes because some classes ended before the two hours and some classes provided additional time to answer questions and clarify instruction.

Qualitative Findings

Teachers, facilitators and the researcher identified four main supports and three main barriers for participants in acquiring pedagogical and content knowledge during the course. The supports include availability of facilitators, shared resources created by the facilitator, hands-on demonstrations provided by the facilitators and participants experiencing curriculum as students. The barriers include course technology issues, irrelevant additions to the course and disorganized breakout rooms.

Supports

Availability of facilitators. Participants reported that all facilitators made themselves available to the teachers in their cohort. Teachers took advantage of their assistance before or after class or during the facilitator's office hours. One teacher said, "There were times when I said I didn't understand something right after class, I would be checking in with the Master Teachers immediately." Another teacher said, "The instructors were just great, they meet before class, after class and are always there to help." Teachers felt more confident knowing that their Master Teachers were available to answer questions before, after, during class, and office hours and by appointment. One facilitator said, "I've even had some teachers when they start, they're apprehensive, you know you don't necessarily have the best attitude about the training and what's going to be expected. But as they go through, they kind of make that turn and they realized that you know we're here to help them and not just burden them with the things that we're trying to do because everything we're doing is directly teaching in the class."

Shared resources provided by facilitator. Facilitator-provided resources, such as self-made YouTube videos and slide presentations that were ready to implement in the classroom were seen as useful by teachers. Many of the facilitators shared their own resources that they use

in their own classrooms. As one teacher said, "One of my instructors for his class did some instructional videos using GeoGebra and posted it on YouTube and shared the links with us so that actually helped me in a lot of ways to navigate GeoGebra." Facilitators also recognized the need to have more content specific instructional videos and resources to share with all cohorts. One facilitator emphasized the importance of "consistency overall with videos that are posted online because …. you've got teachers from all different backgrounds coming in." Other resources that have been helpful to teachers have been social media platforms such as Facebook and YouTube. One teacher said "I started using the PLTW Facebook group for the course. I get more from the Facebook group than I do from the community forum." The Facebook group is an unofficial PLTW group that was created by a PLTW teacher. Whether or not teachers receive supplemental resources depends upon the facilitator, however, and some groups of participants did not benefit from these supports.

Hands-on demonstrations by facilitator. Teachers found it helpful when facilitators gave a step-by step-hands on demonstration. In particular, teachers appreciated hands-on demonstrations to properly draw and dimension figures on isometric and orthographic paper. They found it especially helpful when facilitators modeled good practices using a document camera. Teachers again felt that the breadth and depth of the demonstrations depended on the facilitator. One facilitator said, "I am a big fan doing more hands-on during breakout sessions." But not all facilitators had a document camera to project a demonstration. Some facilitators spent more time with what they were comfortable teaching and dedicated less time to lessons that they did not emphasize in their own classrooms. One teacher said, "Until I actually do it, I'm not going to learn." Another teacher said, "My Master Teacher didn't cover GeoGebra, so I don't even touch it in the classroom." Teachers had just 10 weeks to learn the entire curriculum

and the majority of them expressed the need for direct instruction and practice time with the tools and software so they could return and teach it to their students with confidence. However, if they don't receive the hands-on training from their facilitator, they are less likely to feel confident teaching it to their students.

Experiencing curricular activities as students. Teachers felt that experiencing the same curricular activities and assignments as their students was helpful. One teacher said, "I think it's very nice having the material and having the lessons ready for the teacher. That is something that I have never had teaching technology, I have always had to create my own." Facilitators also perceive that experiencing the curriculum the same as students is crucial to the learning process. As one facilitator put it, "The best way that they are going to learn is going through the same things their students will learn. They need to go through that struggle."

Barriers

Course technology issues. Some participating teachers and facilitators did not have adequate technology and others chose not to use it. Not all teachers had the necessary technology in their classroom including software to implement the course. One facilitator said, "I think another huge barrier that we have with participants is when their district doesn't support them with the correct technology or even like the district isn't supporting them with even the correct supplies and it's like there's a lot kind of going on and I just feel bad." During classroom observations I also noted that not all facilitators had the materials to demonstrate hands-on lessons. Teachers struggled to grasp the use of GeoGebra and Google Sketchup as well as the creation of multi-view drawings when the facilitator did not present guided demonstrations and monitored practice time as part of their instruction. There was one facilitator who chose not to

wear her headset and so her voice was muffled when she spoke, making it was very difficult to understand her.

Irrelevant additions to course. Teachers felt that pedagogical topics and assignments that were not directly related to the content knowledge were a barrier to their learning. Another component teachers felt was irrelevant was when facilitators read the curriculum to them or spent class time reading the assignment instructions. One teacher said that there should be "less of going through and finding where the curriculum is and reading it," adding: "That is something we could do on our own time. I would like to have more situational discussions about how we would teach this or how would we do that with students." Another teacher said, "We've done this before. Just teach us how to teach this course." Teachers also found that some facilitators added their own assignments or asked teachers to complete more designs or sketches than what was being asked of them in the official PLTW assignment. One teacher asked, "Why is she making us do more than what is on the assignment?" One facilitator said, "I would want the prerequisite training to be more content specific….The SolidProfessor[9] is great but it's not directly related to PLTW and what they're having their students do." Another facilitator observed: "SolidProfessor sucks; I personally feel that it's overwhelming to the participants. So, I honestly feel like it's that time barrier because we gave them too much information or too much unrelated information to the actual curriculum. If I have a participant who is really struggling with Google SketchUp then I usually just send them a video of me teaching it."

Disorganized breakout rooms. All facilitators offered breakout sessions throughout the class time. Some breakout rooms were not properly allocated and so teachers found themselves

[9] SolidProfessor is an online video library specific for engineers and K-12 teachers. SolidProfessor membership is automatically given to PLTW teachers as a supplemental on-demand learning platform.

in the wrong groups. Other times the breakout rooms were not planned ahead of time and so teachers had down time until the facilitator organized and dispersed the teachers to their breakout room. Teachers felt flustered because facilitators seemed unprepared. One teacher said, "It was in our very first session. We were supposed to have some breakout groups but the person who started the Zoom didn't know how to setup the groups or they didn't set up the groups before it started." Some teachers would also find themselves confused not knowing what to do or what to discuss during their breakout room. One teacher explained the problem of trying to work together in Zoom without clear instructions: "Because we were on Zoom it was different. If you were in a classroom the expectations are on the board. For the very first time they didn't tell us to make sure you take a picture of this [the instructions from the facilitator's presentation], so we were in a group and we don't know what we're supposed to be doing. We heard it, we saw it, and now we don't remember it. I think that first time we weren't aware. Every other time we knew to take a picture of what we were supposed to be discussing."

Summary

Research Question 2 focused on supports and barriers in acquiring pedagogical and content knowledge during the online course. Both quantitative and qualitative data support the finding that participants voiced less satisfaction with pedagogy than content. This does not seem to be because less time was spent on instructional pedagogy but because teachers were frustrated when facilitators spent class time reading assignment instructions to them or spent too much time on any one assignment. Not all facilitators taught or allocated class time the same way and so the perception of supports or barriers was also dependent on the facilitator teachers had. This further demonstrates how the qualitative data complements the quantitative data. Facilitators on the other hand made several recommendations on how to improve teachers' experience that

would help them acquire the pedagogical and content knowledge. They suggested making the prerequisite training more content specific, providing facilitators with a more detailed guide, using Google Drive as the preferred system to upload, download and share assignments during the core training, replacing SolidProfessor with content specific instructional videos that specifically align with the STEM curriculum, and providing teachers with a detailed course syllabus.

RQ3: How Do Teachers Describe Their Confidence in Implementing a STEM Curriculum after an Online Professional Development Course?

The third research question addressed how teachers describe their confidence in implementing a STEM curriculum after an online PD course. The following sections summarize findings from analyses of the end-of-course satisfaction survey and interview data.

Quantitative Findings

End-of-course survey responses related to confidence from teachers who participated in the online Design and Modeling Core Training in 2018 and 2019 are summarized in Table 5.6. Responses to these survey items were highly correlated with the five items forming a highly reliable scale (Cronbach's alpha = .962). Scale scores ranged from $M = 4.22$ to $M = 4.39$. Teachers felt that the assignments given to them helped them examine their practice ($M = 4.39$, $SD = .889$). They also felt that experiencing the course as a student ($M = 4.36$, $SD = .891$) helped their confidence. Teachers felt that the course built their confidence to facilitate the course with students ($M = 4.32$, $SD = 1.01$). The lowest rated item by teachers was that core training did not sufficiently prepare them to help them prepare their students to persist when solving a challenge while overcoming setbacks ($M = 4.22$, $SD = 1.01$).

Table 5.6

Confidence Questions used from End-of-Course Satisfaction Survey for Analysis

	Item	*n*	*M*	*SD*	*% Excellent (rated 5 on 5-point scale)*
How would you rate online core training on:					
Q4	Preparing me to facilitate engaging hands-on learning using PLTW's activity- project- and problem-based (APB) instructional approach.	123	4.33	.928	59
Q6	Helping me to prepare students to persist when solving a challenge while overcoming setbacks.	122	4.22	1.01	51
Q7	Providing the opportunity to experience select course curriculum materials just as my students will.	122	4.36	.891	57
Q8	Providing assignments that required me to examine my practice.	121	4.39	.889	60
Q11	Building my confidence to return to my classroom and facilitate this PLTW course with students.	122	4.32	1.01	60

Note. Questions 4, 6, 7, 8, and 11 were used to create a confidence scale.

There was no significant change over time (from 2018 to 2019) in teachers' overall ratings of their pedagogical and content knowledge. There was, however, notable variation in average participant satisfaction among the various cohorts that appeared to be related to particular sections or instructors. ANOVA results indicated significant differences ($p = .03$) among sections. As in Tables 5.2 and 5.4, ratings tended to be lower in cohorts with fewer survey respondents. To reiterate, it is possible that only those with more negative views than average responded to the survey in those sections, but no definitive conclusion about this is possible from the data available. Table 5.7 summarizes the variation in confidence scores across

sections (organized from highest to lowest rather than in chronological order of course cohort delivery). Overall, teachers felt comfortable and confident returning to their classrooms to teach the newly adopted curriculum mean (M = 4.33, SD = .881).

Table 5.7

Descriptive Statistics by Cohort for Confidence in Teaching Scale

Cohort	Confidence (Q's 4, 6, 7, 8, 11)		
	n	*M*	*SD*
A	10	4.88	.317
B	7	4.74	.472
C	19	4.48	.862
D	21	4.43	.710
E	18	4.31	.879
F	12	4.30	.838
G	20	4.23	1.08
H	2	4.00	1.41
I	7	3.80	.824
J	4	3.75	.971
K	3	2.87	.987
Total	123	4.33	.881

Note. PLTW considers 5.00 to be the standard for excellence.

Qualitative Findings

All 18 teachers that were interviewed felt confident returning to their classroom and teaching the STEM curriculum. Although all teachers felt comfortable implementing the new course, seven of those 18 teachers also shared concerns over a lack of preparedness. All of the 2018 participants who had a year under their belt felt much more confident than when they implemented the course the first time around. Teachers described several factors that contributed to their degree of confidence in implementing the STEM curriculum after the online PD course.

Factors contributing to confidence. Teachers that felt confident in teaching the new curriculum to their students had an overwhelmingly positive experiences with their facilitators. Their facilitators were available to them and provided rich hands-on demonstrations combined with productive practice time during class. One teacher "said the most helpful sessions was when we drew together and some of those demonstrations of let's do this together." Another teacher said, "we thoroughly covered the material, so I didn't feel surprised by anything."

Teachers that had previous STEM training also felt more confident in teaching the more complex concepts such as technical drafting and 3D Design and modeling. One teacher said, "I was pretty confident but had already had IED[10] training." One experienced teacher shared that the "emphasis should be on the idea that students are creating their own learning and that teachers don't have to know every little thing to be successful at teaching these classes." For many teachers, teaching Design and Modeling for the first time meant learning along with their students.

Factors that undermined confidence. Teachers that felt less confident returning to their classrooms to teach the course attributed this to lack of didactic instruction on complex topics, an absence of clarity on assignments and instruction, and a lack of practice time. One teacher said, "There is a big learning curve for teachers and then we get stressed when we can't teach it to the kids." Another teacher expressed her frustration with the program GeoGebra and said "That program we just did, I not understand it. They went through it really fast, had nobody in our district who knew how to do it." Both interview responses and classroom observations indicated that teachers who lacked confidence with a particular skill probably experienced instruction in which the facilitator did not spend sufficient time demonstrating how to implement the concept.

[10] IED stands for Introduction to Engineering Design and it is a high school PLTW course.

Often facilitators would introduce an assignment and discuss the topic but would not spend enough time demonstrating how to implement it and how to teach it in the classroom. One teacher shared that "doing some of the sketches and never having done those programs or having somebody there who can actually help you was the biggest challenge." Teachers were also concerned about group work. Facilitators tried to model the use of group work for teachers to be able to have their students use it in their learning. Some more experienced teachers found this to be unnecessary as they already felt they knew how to use group work in the classroom. Other teachers, however, struggled with the actual group work assigned in the course. Teachers complained that much time was wasted trying to figure out what the group assignment was. One teacher shared that the "hardest part was figuring out how to manage groups and how to facilitate group work."

Summary

Findings from both quantitative and qualitative data indicate that teachers were relatively confident about implementing the STEM curriculum after taking the PD course, but that their degree of confidence varied depending on their specific classroom experience and the quality of the facilitator's instruction. A main factor in increasing teacher confidence was their experience of hands-on demonstration by the facilitator and sufficient practice time.

Chapter 6

Discussion

The purpose of this investigation was to understand: (a) teachers' overall perceptions of an online STEM PD course, (b) what components of an online STEM PD course are perceived to be supports and barriers in acquiring pedagogical and content knowledge, and (c) how teachers describe their confidence in implementing a STEM curriculum after an online PD course. This final chapter links overarching study findings with the research literature in Chapter 2, using Borko's (2004) PD conceptual framework to organize the discussion. After outlining limitations to the study, this chapter offers recommendations for improving the PLTW online PD programs and discusses how the broader educational community can benefit from the findings.

The PD System

Borko's (2004) model of the professional development system, with its four interacting elements (PD program, the facilitator, the teacher and the context), provides a useful framework for discussing this study's findings. I begin by discussing findings about the PD program itself, illustrating how its use of Desimone's five features of effective PD (e.g. content focused, sustained duration, coherence, active learning, collective participation) met the needs of teachers and resulted in relatively high levels of teacher overall satisfaction with the online STEM PD course. The second element that will be discussed is the PD facilitator and her key role for teachers in acquiring pedagogical and content knowledge. The third element that will be discussed is the teacher as the adult learner and the importance of building confidence to return to the classroom and teach the new skills learned from the PD course. The final element that will be discussed is the context within which the PD took place and its relationship with the learning

issues that teachers experience (e.g. demonstration issues, collaboration issues, technology issues) in the online environment.

PD Program. The PLTW STEM PD program had several features identified by Desimone (2009) as important components of effective PD: content focused, active learning, coherence, sustained duration, and collective participation. The following sections discuss how each of these components characterized the PLTW PD program and contributed to teachers' positive experiences. I also discuss how study findings suggest possible areas for improvement in these areas.

Content focus. Teachers' positive reaction to the content and curriculum focus of the Design and Modeling PD course in this study echoed the findings of Desimone (2009) and others regarding the importance of such a focus. Teachers appreciated how the PD was designed to guide them in completing curricular activities as their students would and to teach them how to implement the new course content. This aligns with the findings of Dede (2006) regarding how teachers learn best when they actively engage with content. Content specific PD instruction leads to increased teacher confidence, as pointed out by Gunter and Reeves (2017). Teachers' reactions to the PD indicated that it included a balance of both pedagogical and content knowledge found in previous studies (e.g., Doering et al., 2009; Graham, 2011; Harris & Hofer, 2011) to be important, though teachers' lower satisfaction ratings with the course focus on pedagogy suggest a potential need for improvement in that dimension.

Sustained duration. This study's findings about the importance to teachers of the sustained duration of the 20 hours of PD over 10 weeks emphasizes another of the essential components of PD identified by previous research (Desimone, 2009; Penuel et al., 2007). At the same time, this study uncovered the importance of more attention to how the PD time is spent

during that sustained time. Teachers felt that the 10-week online PD course was sufficient to cover the material but would prefer to dedicate more time to more complex concepts. One of the biggest issues teachers voiced was the amount of time facilitators spent reading to them, which they thought was a waste of time. Additionally, teachers felt that some of the pedagogical and content activities could have been taught using instructional videos (in an asynchronous format), hence making better use of synchronous class time.

Coherence. Coherence existed between what was taught in the STEM PD course and the participating teachers school's curriculum goals (Desimone, 2009). Even though participating teachers in this study were all required to take the Design and Modeling Course because their school or school district adopted the PLTW curriculum, their learning in the PD was directly related to what they were teaching. Additionally, because teachers were taking the PD course and teaching concurrently, they were able to implement the new skills immediately. This aligns with the findings from Santagata, Kersting, Givvin, and Stigler (2010) and Penuel, Gallagher, and Moorthy (2011) that showed that "the PD they received was directly aligned to the lesson they were to teach immediately after the PD" (Desimone et al., p. 256). The coherence of the PLTW PD program contributed to teachers feeling they were given enough support and enough guidance to integrate pedagogical and content knowledge into their daily instruction.

Active learning. This study's findings echoed the importance of active learning in contributing to teachers' satisfaction with PD. This was due to the number of opportunities during the PLTW PD to offer and receive feedback among peers, share classroom experiences, analyze student work and make presentations (Desimone, 2009). High levels of active engagement were associated with high levels of satisfaction (Downer, Kraft-Sayre, & Pianta, 2009; Fulton & Britton, 2011; Klassen, Chiu, 2010; Shernoff, Sinha, Bressler, & Shultz, 2017;

Reeves, Pedulla, 2011). Teachers felt that learning the STEM skills through PLTW's activity-project- and problem based (APB) instructional approach helped build their confidence to return to the classroom and facilitate the new curriculum.

Collective participation. Teachers' positive response to collaborating, having discussions, and sharing their classroom personal experiences is evident in this study's findings, as participating teachers felt they learned practical knowledge from these collective experiences by sharing with their peers and their facilitators. This was also evident when facilitators encouraged participating teachers to share their own classroom experiences related to the curriculum and also contribute to PLTW's community forum. Facilitators emphasized how PLTW encourages them "establish a community of learners" (Borko, 2004, p. 10). Findings from the current study echo those of multiple research studies (e.g., Desimone et al., 2002; Desimone, Smith, & Phillips, 2013; Garet et al., 2001) about the need "build an interactive learning community" (Desimone et al., 2015; Richardson, Swan, Lownthal, & Ice, 2016; Sing & Khine, 2006).

Facilitator. Findings from this study illustrated the crucial role in teachers' PD experience of the facilitator "who guides teachers as they construct new knowledge and pedagogy" (Borko, 2004, p.4). The current study echoes previous research findings about how facilitators are critical in the success of the PD program overall (Jacobs, Seago, & Koellner, 2017; Rogers, Abell, Lanning, Wang, Musikul, Barker, & Dingman, 2007). It is important to emphasize that this study of PLTW's PD program found wide variation in teacher satisfaction depending on their facilitator. The PLTW facilitators' ability to present the STEM curriculum coherently, provide active and personalized learning, allocate time to complex concepts accordingly, and establish a collaborative environment was critical in teachers' PD experience.

The body of literature on PD confirms with empirical evidence that these features are indeed what lead to changes in teacher practices and ultimately student outcomes (Desimone, 2009; Partnership for 21st Century Skills, 2009; Polly et al., 2015; Porter, Garet, Desimone, Yoon, & Birman, 2000).

Study findings indicated considerable variation in how well organized the facilitators were for leading PD sessions. Teachers' benefited the most from those facilitators who prepared substantially for the classes by having discussed how time was going to be allocated and planned the breakout rooms ahead of time. This was evident in those classes that had smoother instructional delivery with minimal to no downtime due to technology issues, hence making teachers feel that their class time was maximized for learning.

Another source of variation was facilitators' use of teaching resources. Teachers' benefited more from facilitators who were organized and had experience using teaching resources such as a document camera and curriculum related materials such as isometric paper. Teachers also appreciated learning tips on how to introduce new lessons and how to implement complex concepts in their classrooms. Other facilitators did not have or use these resources, and teacher learning was affected. When teachers are able to see a demonstration of the use of the curriculum specific materials, they are more likely to implement them with confidence in their own classroom (Ertmer et al., 2010; Phu, Vien, & Cepero, 2014; Holmes, Singer, & MacLeod, 2010).

While all the cohorts (sections) of PD participants were led by a team of three facilitators, classroom observations uncovered variation in how smoothly the members of the facilitator team interacted with each other. Teachers voiced higher levels of satisfaction with the online STEM PD course when facilitators were actively engaged and responsive during each session. This

aligns with the work of Lu et al. (2006) and Reeves et al. (2011) that helped explain how active facilitators help teachers have a more positive PD experience. Teachers felt more satisfied when all three facilitators were consistent with the PD program curriculum and goals. For example, when teachers asked questions but received inconsistent answers from their facilitators, they felt confused or when facilitators had different expectations about the amount of work that teachers needed to complete.

Teachers as learners. The findings from this study show that teachers as adult learners begin the online STEM PD course with different abilities, diverse backgrounds and prior experiences. Therefore, teachers vary in response to the same PD (Borko, 2004; Wilsey, Kloser, Borko, & Rafanelli, 2020). Because teachers come from diverse backgrounds their ability to relate to the content is also affected. For example, teachers that had prior engineering training voiced more confidence in implementing the 3D modeling software Google Sketchup and teachers with previous math experience were more comfortable implementing the software Geogebra. Overall teachers may be more satisfied in the PD course if they were grouped by their background and previous experience with STEM concepts.

Context. As Borko (2004) points out, PD takes place within a particular context that needs to be taken into consideration. In this case, the PLTW PD took place at the same time that teachers were teaching course content to their students. It also took place in an online format. Both of these contextual factors influenced teachers' experiences.

PD for course content concurrent with teachers teaching course. As noted in Chapter 5, teachers had mixed reactions about taking the PD course while teaching the course to students. Some felt overwhelmed taking the course while teaching because they underestimated the amount of time needed to complete their assignments. The other complaint that teachers voiced

was from those who were teaching ahead of learning the curriculum. This caused frustration among those participants' because they felt they were learning new skills after they had already taught them. The majority of teachers, however, did enjoy learning and teaching concurrently since they were implementing new skills in the classroom after learning them in their PD course. The majority of teachers found this extremely helpful since they were able to return to the PD course and discuss and reflect on their experiences with other teachers.

Online learning. The online context was relevant to participants' experiences. Some teachers who voiced a preference for taking the PD course face-to-face over the summer (before teaching it to students) were teachers that had previously taken a PLTW training in person or teachers who did not feel comfortable taking an online course. This was not the majority. In fact, most teachers preferred taking the course online because it offered flexibility and was more convenient for their schedules. This course differs from the face-to-face version conducted in the summer in that teachers have less planning and preparation time. This could affect teachers' learning, and confidence in being able to deliver the STEM curriculum to students. The following sections include specific issues encountered during online learning and are explained below.

Balance of synchronous and asynchronous learning. Teachers' mixed reactions to the primarily synchronous format of this online PD in this study reflect previous research findings about the importance of a more balanced combination of synchronous and asynchronous sessions. A combination of synchronous and asynchronous sessions is recommended in online courses because it allows for both flexibility in teachers' schedules and community building (Branon et al., 2001; Huang & Hsiao, 2012; Mick & Middlebrook, 2015; Oztok et al., 2013; Pearl & Vasquez, 2016). Although instructional delivery in this study's online PD course is

predominantly offered in synchronous sessions, the training does include some asynchronous instructional videos. Prior literature suggests that participants who have only synchronous discussions lack those that involve "cognitive and metacognitive skills" (Chen et al., p. 1155; Oztok et al., 2013). Both teachers' and facilitators voiced a need for more content specific instructional videos throughout the prerequisite training as well as in their core training. Because teachers enter the program with different abilities, prior knowledge asynchronous sessions allow for participants to partake in activities on their own timetable (Branon et al., 2001; Huang et al., 2012; Nandi, Hamilton, & Harland, 2012).

Demonstration issues. The majority of teachers in this study wanted more time dedicated to online demonstrations and more guided practice with curricular activities. Especially in online STEM PD courses, demonstration and practice time are crucial in teacher learning (Darling-Hammond et al., 2017; del Valle et al., 2009; Lim et al., 2013). Another issue that I observed related to demonstrations was that not all facilitators had the necessary materials or equipment readily available to demonstrate lessons such as a document camera. Ensuring sufficient resources for demonstrations is critical for STEM PD (Chen, Bastedo, & Howard, 2018; Yang, 2017).

Collaboration issues. Online collaboration is necessary to build teacher confidence and establish a learning community (Dede, 2006; Dede et al., 2009). Teachers voiced several issues about collaborative time during PD sessions. Teachers did not appreciate being grouped with other teachers from different time zones because it was difficult to work on projects together. Another issue that teachers voiced was being grouped in breakout sessions without clear instructions. In order for collaboration to be effective teachers need to be given opportunities to actively discuss with other teachers and their facilitator (Dunlap, Verma, & Johnson, 2016). It's

through these collaborative opportunities that teachers share classroom experiences, learn from each other and in turn build their confidence (Durksen, Klassen, & Daniels, 2017; Dunlap, Lowenthal, 2018).

Technology issues. In general, technology presented few problems in the STEM PD course. There were very few technological issues related to the web conferencing tool Zoom. The majority of the teachers in the PD program had prior experience taking an online course. One issue encountered during the study was teachers not having the appropriate materials or the correct version of the software on their computer. Some of the problem was due to the teachers' district not providing them with the necessary resources. In some cases, there was negligence or ignorance on the teacher's part. Both district and school leaders should make sure that teachers sent to specialized PD have the necessary resources to be successful (Birman et al., 2007; McGinnis et al., 2004; Pianta, 2011; Rannastu-Avalos & Siiman, 2020). These teachers were afraid of being isolated, falling behind in their course work and unable to teach their students. PLTW incorporates a preliminary meeting before the 10 synchronous sessions to review technological requirements and other prerequisite items that were necessary to checkoff before starting the first session, but even with this meeting there are teachers who do not follow through with all of the prerequisite items. Another issue that was voiced was that teachers needed to be shown not told how to use the features in Zoom such as screen share and how to use the whiteboard effectively. Another technology issue was the uploading and downloading of assignments on the LMS. Both facilitators and teachers used Google Drive to share and collaborate on assignments even though it is not endorsed by PLTW. Teachers and facilitators felt more comfortable and familiar using Google Drive. They found the LMS to be clunky and

onerous because they had to download the assignment, complete the tasks then upload it again while on Google Classroom there is no need for downloading and uploading.

Teachers experienced some technological issues at their professional setting that might have affected their learning and teaching. Although not the majority, some teachers did not have all the necessary software installed on student computers or all of the content specific materials to teach the course. This was due to districts or schools not ordering materials on time or not having dedicated information technology personnel to ensure student computers have everything they need. Another technology issue that might have affected implementing the STEM course was that teachers felt the student curriculum available to them was text heavy, difficult to follow and cumbersome to download and upload assignments using PLTW's LMS. Teachers felt that it was easier to modify the lessons and place them on Google Drive to make it easily accessible to their students since the majority of schools used Google Education as their LMS.

Limitations

This study has several limitations. As a case study of a particular PD program, focused on a particular STEM course for students, there are limits in how far it can be generalized. It may be less relevant for considerations of PD programs that are not STEM-related and not conducted online. Secondly, the participant survey response rates were relatively low on some of the session surveys, which could indicate bias. Given that sections with smaller response rates had more negative results, it is possible that only those participants who had negative reactions to the course took the time to complete the survey in those sections. Conclusions about variability in facilitator quality need to be interpreted with caution. Third, it is possible that interview respondents may not be representative of all PD participants and facilitators. Finally,

interpretations of data could be influenced by unknown biases from my deep personal connections with PLTW.

Despite these limitations, the study should be useful not only to the PLTW organization itself, but also to other providers of PD for STEM teachers in the online space. Many of the findings about how the PLTW PD program incorporated elements of effective PD identified by Desimone (2009) and effective online learning practices will be useful to others.

Recommendations

Choice of LMS to better serve participating teachers. PLTW may want to consider user preferences in its choice of an LMS. Although PLTW may prefer a more robust LMS that allows for increased security and functionality, facilitators, teachers, and students prefer using Google Education over the PLTW LMS because of its user friendliness and usability. The majority of facilitators and teachers already share resources via Google Drive during the PD course. I am recommending that PLTW choose an LMS that is more user friendly and integrates well with G Suite for Education.

Design of prerequisite learning modules. Prerequisite learning modules should be content specific to help the teachers succeed in the online PD course. Learning modules should incorporate instructional learning videos for major topics and provide hands-on learning activities to ensure that teachers have mastered those basic skills they need before engaging with the actual PD course. Because of the varied level of experience with which teachers come into the PD course, these learning modules should address the needs of the least experienced teacher and allow the more experienced teacher to move quickly through the module. I am recommending that PLTW enhance the prerequisite learning modules by incorporating a content specific video for each of the major topics in the PD course.

Training of facilitators to provide more common, coherent experience across in sections. The findings of this study showed that PD experiences are highly dependent on the facilitator. It is important to provide facilitator training that creates more standardization across the PD experience. The following recommendations focus on the facilitator training related to demonstrations, use of resources and tools, structure and pacing of instruction, and combination of synchronous and asynchronous lessons.

Demonstrations. This study identified the need for more and better demonstrations of the use of course materials and technology, such as Zoom features or particular Design and Modeling software. Facilitator training needs to emphasize how demonstrations should be a more integral and consistent part of the PD curriculum. I am recommending that PLTW enhance their facilitator trainings by creating a library of best practices within PLTW on how to give effective demonstrations in the online environment with tools such as a document camera. I am also recommending that facilitator training specify the particular demonstrations that should be given and the suggested amount of time that should be spend conducting each demonstration.

Use of resources and tools. Teachers benefited from facilitators who demonstrated and shared resources and tools that teachers should use in teaching the PLTW curriculum. Because some teachers felt that in many cases they completed the PD course without a solid understanding of using the resources and tools that they are supposed to expose the students to I am recommending that PLTW enhance teachers learning experience by asking facilitators to use the same tools and resources to teach complex lessons online (e.g., a document camera). Additionally, I recommend that PLTW develop their own content specific instructional videos instead of using a third party (e.g., SolidProfessor) so that all facilitators can be consistent in the

content knowledge they are sharing. Although SolidProfessor is a great resource, findings from this study indicate that it is not content specific enough for the PD course.

Structure and pacing of instruction. Teachers often complained that facilitators read the content material to them instead of demonstrating how to learn the new skill. One of the most prevalent issues with the PD course was the lack of consistency with the way facilitators structured the delivers of content and the pacing at which it was delivered. There should be a greater level of consistency in the way facilitators pace and deliver the content so as to ensure a more even PD experience for teachers. Didactic methods of instruction need to be examined and wherever possible replaced with more of a focus on hands-on activities and demonstrations. Facilitators should not be reading instructions to the teachers. I am recommending that PLTW provide facilitators with a more detailed instructional guide that includes how to deliver course content to adults in an online environment.

Combination of synchronous and asynchronous lessons. The findings of this study showed that teachers need more content specific instruction on more complex topics. I am recommending that PLTW include asynchronous sessions using content specific instructional videos for teachers as part of the PD course (e.g., 3-part video on how to design various shapes using Google Sketchup or a 4-part video on how to create orthographic drawings using various shapes). Instructional videos would allow teachers to rewind, pause, and offer opportunities to practice the new skill without having to rush (Borup, West, & Graham, 2012; Choi et al., 2005; Semich et al., 2018). Teachers felt that they prefer synchronous sessions to learn content and sharing opportunities to teach the new skills learned and asynchronous sessions to practice. Another use of instructional videos would be to teach pedagogical activities. Novice STEM

teachers might need PD for developing their pedagogical and content knowledge with an emphasis on content knowledge more so than their more experienced teacher counterparts.

Conclusion

As online PD continues to expand, there is a need for effective online PD for teachers especially in the area of STEM. We need to learn more about how to deliver STEM effectively in an online environment to teachers as STEM PD involves many hands-on demonstrations with specialized materials and software. Given the variation in teachers' experience depending on the particular PD facilitator, further research focused on the training of online PD facilitators could be a useful addition to the research literature. After development of a facilitator training module and preliminary studies of its usability and feasibility, it could be useful to conduct a randomized controlled trial to compare outcomes for participants whose facilitators participated in such a training and those who did not. Other future research could include measuring the impact on student outcomes after teachers' participation of an online STEM PD course. It would also be helpful to conduct studies comparing the effectiveness of online STEM PD course versus a similar face-to-face STEM PD course on student achievement.

This study identified many ways in which the PLTW online training incorporates the components of effective PD identified by Desimone (2009) and others. At the same time, this study has also identified areas where changes could contribute to even more positive learning for the PD participants. As PLTW and other online PD providers continue to engage in a continuous improvement process, these findings may be useful to consider.

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Appendix A

Email Recruitment Script for PD Participants

September 13, 2019

Dear PLTW teachers:

My name is Yolanda Valencia, and I am doctoral student at Johns Hopkins University (as well as a teacher who has worked with Project Lead the Way in the past). I am contacting you to invite you to participate in a research study about teachers' experiences in an online STEM course. I am working with Dr. Martha Mac Iver, faculty member and doctoral advisor at the Johns Hopkins School of Education. Dr. Bertram CEO of PLTW and all members of PLTW's Senior Leadership Team approve this research.

Research Purpose: The main purpose of this research is to understand and describe the experiences of participating teachers and facilitating teachers in the online Design and Modeling course.

Research Participation: Participating in the study is completely voluntary and there are no consequences for declining to participate. Participation involves completing a 5 minute online survey and a 20 minute interview by phone or ZOOM about your experiences in the online Design and Modeling course. I will also be observing silently during many of the online Design and Modeling course sessions in 2019, which will not affect the classroom experience or take any time of class participants or facilitators. Please contact me (see information below) if you do not want to agree to me observing in your online class (letting me know in which cohort section you are enrolled).

Confidentiality: Teacher names and your survey responses will be kept confidential and will not be shared with anyone. Interview responses will be kept confidential and be seen only by myself and Dr. Mac Iver from Johns Hopkins University. Reporting of findings will use pseudonyms rather than teacher names.

Contact Information: Please do not hesitate to contact me with any questions by email, yvalenc1@jhu.edu or by phone, (786) 853-9736. Additionally, for further information you may contact Dr. Martha Mac Iver at mmaciver@jhu.edu.

Next Steps: If you are interested in participating in the survey and interview, please follow this link to an online survey form. {Insert Link}.

Should you decide to decline this opportunity, please follow this link {Insert Link}. Once you provide your name, I will omit you from all future email communications.

Many thanks for your consideration.
Ms. Yolanda Valencia
Doctoral Student Investigator

Appendix B

Informed Consent Form

Johns Hopkins University
Homewood Institutional Review Board (HIRB)

Research Participant Informed Consent Form

Study Title:	Online Professional Development for STEM Teachers
Principal Investigator (PI):	Dr. Martha Mac Iver, Associate Professor, School of Education Johns Hopkins University 2800 N. Charles St. Suite 420 Baltimore, MD 21218, 410-516-8256 This research will be done for a Dissertation in the EdD program of the Schools of Education at Johns Hopkins University and will be conducted by Yolanda Valencia
Date:	September 13, 2019

You are being asked to join a research study. Participation in this study is voluntary. Even if you decide to join now, you can change your mind later.

Research Summary (Key Information):
The information in this section is intended to be an introduction to the study only. Complete details of the study are listed in the sections below. If you are considering participation in the study, the entire document should be discussed with you before you make your final decision. You can ask questions about the study now and at any time in the future.

The purpose of this study is to describe and understand teachers' experiences in the Project Lead the Way (PLTW) online professional development Design and Modeling course. It involves a 20 minute interview (and additional 5 minute online survey for teacher PD participants). Benefits to participation in the study could include the opportunity to provide feedback that could improve the experience of teachers in future courses. There are no costs or significant risks of participation in the study.

Why is this research being done?
This research is being done to better understand teachers' experiences in PLTW's online professional development Design and Modeling course. The research may identify ways in which the course may be improved for future participants.

This research will be done for a Dissertation in the EdD program of the School of Education at Johns Hopkins University.

People who have participated as teachers or facilitators with PLTW's online professional development Design and Modeling course may join the study.

What will happen if you join this study?
If you agree to be in this study, we will ask you to do the following things:

- ***Participate in one 20 minute interview (by phone or videoconferencing) about your experience in the online Design and Modeling course.***

Audio recordings:
As part of this research, we are requesting your permission to create and use an audio recording of the interview. Any audio recording will not be used for advertising or non-study related purposes.

You should know that:

- You may request that the audio recording be stopped at any time.
- If you agree to allow the audio recording) and then change your mind, you may ask us to destroy that imaging/recording.

Please indicate your decision below by checking the appropriate statement:

_____I **agree** to allow the study to make and use audio recordings of me for the purpose of this study.

_____I **do not agree** to allow the study team to make and use audio recordings of me for the purpose of this study.

How long will you be in the study?
You will be in this study for about 20 minutes.

What are the risks or discomforts of the study?
You may get tired or bored when we are asking you questions, or you are completing questionnaires. You do not have to answer any question you do not want to answer.

There is the risk that information about you may become known to people outside this study. The risks associated with participation in this study are no greater than those encountered in daily life.

Are there benefits to being in the study?
There is no direct benefit to you from being in this study.

This study may benefit society if the results lead to a better understanding of online professional development for teachers.

Your participation in this study is entirely voluntary. You choose whether to participate.

If you decide not to participate, there are no penalties, and you will not lose any benefits to which you would otherwise be entitled.

What are your options if you do not want to be in the study?
Your participation in this study is entirely voluntary. You choose whether to participate.
If you decide not to participate, there are no penalties, and you will not lose any benefits to which you would otherwise be entitled.

Will it cost you anything to be in this study? No.

Will you be paid if you join this study? No.

Can you leave the study early?
- You can agree to be in the study now and change your mind later, without any penalty or loss of benefits.
- If you wish to stop, please tell us right away.

How will the confidentiality of your data be protected?
Any study records that identify you will be kept confidential to the extent possible by law. The records from your participation may be reviewed by people responsible for making sure that research is done properly, including members of the Johns Hopkins University Homewood Institutional Review Board and officials from government agencies such as the National Institutes of Health and the Office for Human Research Protections. (All of these people are required to keep your identity confidential.) Otherwise, records that identify you will be available only to people working on the study.

What other things should you know about this research study?

What is the Institutional Review Board (IRB) and how does it protect you?
This study has been reviewed by an Institutional Review Board (IRB), a group of people that reviews human research studies. The IRB can help you if you have questions about your rights as a research participant or if you have other questions, concerns or complaints about this research study. You may contact the IRB at 410-516-6580 or hirb@jhu.edu.

What should you do if you have questions about the study?
Call the principal investigator, Dr. Martha Mac Iver at 410-516-8256. If you wish, you may contact the principal investigator by letter. The address is on page one of this consent form. If you cannot reach the principal investigator or wish to talk to someone else, call the IRB office at 410-516-5680.

You can ask questions about this research study now or at any time during the study, by talking to the researcher(s) working with you or by calling student investigator Yolanda Valencia at (786) 853-9736.

If you have questions about your rights as a research participant or feel that you have not been treated fairly, please call the Homewood Institutional Review Board at Johns Hopkins University at (410) 516-6580.

What does your signature on this consent form mean?

Your signature on this form means that: You understand the information given to you in this form, you accept the provisions in the form, and you agree to join the study. You will not give up any legal rights by signing this consent form.

_____

Participant Name

_____

Signature of Person Obtaining Consent (Investigator or HIRB-Approved Designee) Date

Appendix C

Design and Modeling Course Participant Teacher Survey

By completing this survey you are consenting to be this research study. Your participation in the research is voluntary and you can stop at any time. Complete this questionnaire only if you are interested in being contacted for a follow up interview about your experiences in the online Design and Modeling course.

This study is being conducted by Yolanda Valencia, a doctoral student at the Johns Hopkins University School of Education who has worked as a master teacher for Project Lead the Way (PLTW).

Your answers to these questions and the interview questions will be kept confidential and seen only by the student and her advisor at Johns Hopkins University, Dr. Martha Mac Iver. At the end of the survey you will be asked to indicate if you are interested in being contacted for a follow up interview.

1. First Name _____
2. Email Address _____
3. D&M online PD Master Teachers' Names: _____ _____

Background questions about you:

4. Sex:
   - ❒ Male
   - ❒ Female
5. Race/Ethnicity
   - ❒ Asian/Pacific Islander
   - ❒ American Indian
   - ❒ Black/African American
   - ❒ Hispanic/Latino
   - ❒ White/Caucasian (non-Hispanic)
   - ❒ Other
6. What time zone do you live in?
   - ❒ Eastern
   - ❒ Central
   - ❒ Mountain
   - ❒ Pacific
7. Years of teaching experience
   - ❒ Less than 1
   - ❒ 1-2
   - ❒ 3-5
   - ❒ 6-10
   - ❒ 11-15
   - ❒ 16-20
   - ❒ More than 20

8. Years of teaching PLTW courses (if any)
    - ❒ Less than 1
    - ❒ 1-2
    - ❒ 3-5
    - ❒ 6-10
    - ❒ 11-15
    - ❒ 16-20
    - ❒ More than 20
9. In which year did you participate/are you participating in the online Design and Modeling course?
    - ❒ 2018
    - ❒ 2019
10. Have you participated in an online course before Design and Modeling?
    - ❒ Yes
    - ❒ No
11. Have you participated in other PLTW trainings in the past?
    - ❒ Yes
    - ❒ No
12. Is/was the PLTW's Online Core Training for Design and Modeling something you look/looked forward to?
    - ❒ Yes
    - ❒ No
13. Which of the following best describes the area or setting of your school?
    - ❒ Rural
    - ❒ Urban/City Area
    - ❒ Suburban
14. What relevant subject matter state certification do you hold?
    - ❒ Engineering
    - ❒ Science
    - ❒ Math
    - ❒ Physical Science
    - ❒ Chemistry
    - ❒ Life Science
    - ❒ Earth Science
    - ❒ Business
    - ❒ Career and Technical Education
    - ❒ Computer Science
    - ❒ Other (please specify)
15. What is the highest degree you have received?
    - ❒ Bachelor's degree
    - ❒ Master's degree
    - ❒ Ed.S.
    - ❒ Doctoral degree

16. I am willing to be contacted to participate in a 20 minute interview about my experience in the PLTW online Design and Modeling Course
    - ❒ Yes
    - ❒ No

Thanks so much for completing the survey. I will be contacting many (if not all) of those who agree to be interviewed within the next several weeks to schedule the interview.

Appendix D

Email Recruitment Script for PD Facilitators

September 13, 2019

My name is Yolanda Valencia, and I am doctoral student at Johns Hopkins University (as well as a teacher who has worked with Project Lead the Way in the past). I am contacting you to invite you to participate in a research study about teachers' experiences in an online STEM course. I am working with Dr. Martha Mac Iver, faculty member and doctoral advisor at the Johns Hopkins School of Education. Dr. Bertram CEO of PLTW and all members of PLTW's Senior Leadership Team approve this research.

Research Purpose: The main purpose of this research is to understand and describe the experiences of participating teachers and facilitating teachers in the online Design and Modeling course.

Research Participation: Participating in the study is completely voluntary and there are no consequences for declining to participate. Participating in the study involves a 20 minute interview by phone or ZOOM about your experiences in the online Design and Modeling course. I will also be collecting observation data and field notes during the online Design and Modeling course sessions in 2019 to triangulate the interview data. Observations will be silent and will not affect the classroom experience or take any time of class participants or facilitators. Please contact me (see information below) if you do not want to agree to me observing in your online class (letting me know which cohort section you teach).

Confidentiality: Interview responses will be kept confidential and be seen only by myself and Dr. Mac Iver from Johns Hopkins University. Reporting of findings will use pseudonyms rather than teacher names.

Contact Information: Please do not hesitate to contact me with any questions by email, yvalenc1@jhu.edu or by phone, (786) 853-9736. Additionally, for further information you may contact Dr. Martha Mac Iver at mmaciver@jhu.edu .

Next Steps: If you are interested in participating in this research, please follow this link to an online consent form that provides more details about the study. {Insert Link}. Please read the information and type your name at the end; your typed name serves as your signature. I will contact you about setting up a time for an interview.

Many thanks for your consideration.

Ms. Yolanda Valencia
Doctoral Student Investigator

Appendix E

PLTW satisfaction survey measures (archival)

PD facilitators – PLTW Master Teachers
Participants – PLTW core training participants (adult learners)

Research Questions	Constructs	Measures (variables)
RQ1 What are teachers' perceptions of an online STEM professional development course?	Overall Course Evaluation	Q1 Providing prerequisite materials that strengthened knowledge skills and mindsets needed to successfully engage in Core Training. Q2 The pace at which material was covered. Q3 Providing opportunities to experience conceptually challenging concepts from the course curriculum with the guidance of Master Teachers. Q5 Helping me understand how the knowledge and skills students learn in PLTW develop career connections. Q12 Providing assignments outside of synchronous online sessions that consisted of exercises of an appropriate length and difficulty. Free Response: If you rated any of the items in this section as Fair or Poor please provide additional information As you consider the PLTW Master Teacher as well as the Online Core Training content on a scale of 0 to 10 how likely are you to recommend the PLTW Online Core Training experience to another teacher or administrator? Free Response: Please provide additional information that pertains to the above rating.

RQ2 What components of an online professional development course function as supports and barriers for teachers in acquiring pedagogical and content knowledge?	Pedagogical and Content Knowledge	Q9 Providing an adequate focus on course content. Q10 Providing an adequate focus on pedagogy
RQ3 How do teachers describe their confidence in implementing a STEM curriculum after an online professional development course?	Confidence	Q4 Preparing me to facilitate engaging hands-on learning using PLTW's activity- project – and problem-based (APB) instructional approach. Q6 Helping me to prepare students to persist when solving a challenge while overcoming setbacks. Q7 Providing the opportunity to experience select course curriculum materials just as my students will. Q8 Providing assignments that required me to examine my practice. Q11 Building my confidence to return to my classroom and facilitate this PLTW course with students.

Appendix F

Semistructured Interview Protocol – Participants

Script:

Say, "Thank you for agreeing to participate in this interview. I am conducting a study to better understand what makes a successful online teacher professional development course particularly in project-based STEM."

Say, "Please feel free to share as much as you would like. If you have any questions or concerns at any time and would like to stop the interview, please don't hesitate to let me know. With your permission, I will record our session. This recording will then be uploaded to my password protected Google Drive. The interview transcription will not be shared with anyone other than my adviser, and dissertation committee. At no time will I be sharing your name or other identifying information. This work will be reported in my findings for my dissertation."

Say, "Do you have any questions before we start?"

Interview Questions:
Say the question and allow for interviewee to respond.

PD Participant Characteristics Questions

Say, "First, I have a few questions about your background."

1. How many years of teaching experience do you have?
2. Have you participated in an online course before?
3. Have you participated in other PLTW courses in the past?
4. How many years of teaching experience to do you have teaching a PLTW course?

Say, "Now I would like to hear more about your experience with the Design and Modeling course."

5. Why did you decide to participate in the PLTW course?
6. How did your participation in the online Design and Modeling course change your thinking about online learning?

Professional Development Questions

Course Design

1. How would you describe your online STEM course experience overall?
2. How did the structure and pace of the course support or hinder your learning?
3. How was your experience using ZOOM?

4. Is there anything that you would change about PLTW's online Design and Modeling course?

Self-efficacy in Teaching

5. How confident did you feel teaching the new curriculum to your students after completing the course?
6. What part of the core training did you feel less confident in teaching?
7. How would you describe your comfort level teaching the Design and Modeling course to your students?

Pedagogical and Content Knowledge

8. What resources helped you the most in learning the new curriculum throughout your core training (e.g. supplemental materials from your teacher, collaborating with other teachers, practice time, content-specific instructional videos, access to facilitator-office hours)?
9. Was there anything that hinder your learning during core training (e.g. down-time, personal technology issues)? Could you tell me more about that?
10. How would you describe the balance between content and pedagogy during core training?
11. What recommendations do you have for PLTW to help teachers learn the pedagogical content knowledge better?

Closing

Say, "Thank you so much for agreeing to do this interview with me today. I appreciate your time and thoughtful responses to my questions. If a thought or idea occurs to you after I leave, and you would like to talk again, please feel free to email or call me.

Appendix G

Semistructured Interview Protocol – PD Facilitators

Script:

Say, "Thank you for agreeing to do this interview. I am conducting a study to better understand what makes a successful online teacher professional development course particularly in project-based STEM."

Say, "Please feel free to share as much as you would like. If you have any questions or concerns at any time and would like to stop the interview, please don't hesitate to let me know. With your permission, I will audio record our session. This recording will then be uploaded to my password protected Google Drive. The interview transcription will not be shared with anyone other than my advisor, and dissertation committee. At no time will I be sharing your name or other identifying information. This work will be reported in my findings for my dissertation."

Say, "Do you have any questions before we start?"

Interview Questions:
Say the question and allow for interviewee to respond.

PD Facilitator Characteristics Questions

Say, "First I have a few questions about your background.

1. How many years of teaching experience do you have?
2. How many years have you been an online master teacher with PLTW?
3. How would you describe your confidence level after completing the Master Teacher online training?
4. How did your participation in teaching the online Design and Modeling course change your thinking about online learning?

Say, "Now I would like to hear more about your experience with the Design and Modeling course."

Professional Development Questions

Pedagogical and Content Knowledge

1. How would you describe your online teaching experience overall?
2. What components of the course serve as supports and/or barriers for participants to learn?
3. How do you perceive your participants' confidence after completing the online course?
4. What resources help you the most in teaching the online course? (e.g. Zoom, software, Google Drive; PLTW's scope and sequence, PLTW's online master teacher training)

5. What additional resources would help your students learn the content better? (e.g. more practice time, content-specific instructional videos, access to facilitator-office hours)
6. What changes would you recommend about the online course in order to improve your students' experience?

Closing

Say, "Thank you so much for agreeing to do this interview with me today. I appreciate your time and thoughtful responses to my questions. If a thought or idea occurs to you after I leave, and you would like to talk again, please feel free to email or call me."

Appendix H

Online Classroom Observation Protocol

Master Teacher 1 Code: _____
Master Teacher 2 Code: _____
Tech Support Master Teacher Code: _____
Observation Date: _____
Cohort: A B C D E
Week/Class: 1 2 3 4 5 6 7 8 9 10

Course Components	**Time Expended**	**Observations of Inservice Teacher Engagement (detailed description and screenshots)**
Content instruction		
Instructional Pedagogy		
Practice time with new content/technology		
Collaboration with facilitator or other teachers		
Down time due to issues with technology		
Down time not due to technology issues		

Appendix I

Summary Matrix

Research Questions	Constructs	Measures/Data Collection Tool	Data Analysis
RQ1: What are teachers' perceptions of an online STEM professional development course?	Satisfaction with Course Design and Implementation • Synchronous vs asynchronous vs blended • Content vs pedagogy • Timing/pace • Collaboration • Web Conferencing Technology	PLTW satisfaction surveys (archival) Semistructured interviews (PD participants)	Descriptive statistics Thematic coding
RQ2: What components of an online professional development course function as supports and barriers for teachers in acquiring pedagogical and content knowledge?	Pedagogical and Content Knowledge	Semistructured interviews (PD participants and facilitators) Online classroom observations Researcher's journal and notes	Descriptive statistics Thematic coding
RQ3: How do teachers describe their confidence in implementing a STEM curriculum after an online professional development course?	Confidence	PLTW satisfaction surveys (archival) Semistructured interviews (PD participants)	Descriptive statistics Thematic coding

Appendix J

Design and Modeling Participant Survey Response from Archival Data

Descriptive Statistics by Cohort

Item	Cohort	*n*	*M*	*SD*
Q1	A	10	4.7	0.675
	B	7	4.43	0.535
	C	19	4.47	0.772
	D	21	4.14	1.014
	E	12	4.08	0.996
	F	18	4.28	0.895
	G	20	4	1.338
	H	2	3	0
	I	7	3.71	1.113
	J	4	3	1.826
	K	3	3	1
	Total	123	4.14	1.051
Q2	A	10	4.6	0.699
	C	19	4.37	0.831
	D	20	4.3	0.733
	B	7	4.29	0.756
	G	20	4.15	1.04
	F	18	4.06	0.873
	H	2	4	1.414
	E	12	3.83	1.267
	I	7	3.71	1.113
	J	4	3.25	1.5
	K	3	2	1.732
	Total	122	4.1	1.024
Q3	A	10	4.9	0.316
	B	7	4.86	0.378
	D	21	4.48	0.68
	C	19	4.42	1.071
	F	18	4.33	0.907
	E	12	4.33	0.888
	G	20	4.2	1.105
	J	4	3.75	1.258
	I	7	3.71	1.113
	H	1	3	.
	K	3	2.33	1.528
	Total	122	4.31	0.988

Q4	A	10	4.8	0.632
	B	7	4.71	0.488
	F	18	4.44	0.922
	D	21	4.38	0.805
	C	19	4.37	0.955
	G	20	4.35	0.875
	E	12	4.33	0.888
	H	2	4	1.414
	I	7	3.86	0.9
	J	4	3.5	1.291
	K	3	2.67	1.528
	Total	123	4.33	0.928
Q5	A	10	4.7	0.675
	C	19	4.58	0.507
	B	7	4.57	0.535
	D	21	4.24	0.889
	F	18	4.22	0.943
	E	11	4.09	0.831
	H	2	4	1.414
	J	4	3.75	0.957
	I	7	3.71	1.113
	G	19	3.63	1.422
	K	3	2	1.732
	Total	121	4.13	1.048
Q6	A	10	4.9	0.316
	B	7	4.71	0.488
	C	19	4.26	0.991
	D	21	4.24	0.995
	F	18	4.22	0.943
	E	11	4.18	0.751
	G	20	4.15	1.348
	H	2	4	1.414
	J	4	3.75	0.957
	I	7	3.71	1.113
	K	3	3	1
	Total	122	4.22	1.008
Q7	A	9	4.89	0.333
	B	7	4.71	0.488
	C	19	4.58	0.961
	D	21	4.52	0.68
	F	18	4.33	0.907
	G	20	4.25	1.07
	E	12	4.17	1.03

	J	4	4	0.816
	H	2	4	1.414
	I	7	3.71	0.756
	K	3	3.33	0.577
	Total	122	4.36	0.891
Q8	A	10	4.8	0.422
	B	7	4.86	0.378
	C	19	4.68	0.749
	D	21	4.57	0.676
	E	11	4.36	0.809
	F	18	4.22	0.878
	G	20	4.15	1.226
	H	2	4	1.414
	I	7	4	0.816
	J	3	4	1
	K	3	3	1
	Total	121	4.39	0.889
Q9	A	10	4.7	0.483
	B	7	4.71	0.488
	C	19	4.47	0.841
	D	20	4.4	0.754
	E	11	4.18	1.079
	F	18	4.33	0.907
	G	20	4.35	0.813
	H	2	4	1.414
	I	7	3.86	0.9
	J	4	4	0.816
	K	3	2.67	1.155
	Total	121	4.32	0.868
Q10	A	0	.	.
	B	0	.	.
	C	0	.	.
	D	21	4.24	0.889
	E	11	4.09	1.044
	F	0	.	.
	G	20	4.25	1.118
	H	2	4	1.414
	I	0	.	.
	J	4	3	1.633
	K	3	2.33	1.528
	Total	61	4.03	1.154
Q11	A	10	5	0

	B	7	4.71	0.756
	C	19	4.53	0.964
	D	21	4.43	0.811
	F	18	4.33	0.907
	E	11	4.27	0.905
	G	20	4.25	1.251
	H	2	4	1.414
	I	7	3.71	0.756
	J	4	3.5	1.291
	K	3	2.33	1.528
	Total	122	4.32	1.014
Q12	A	10	4.6	0.966
	B	7	4.86	0.378
	C	19	4.47	1.02
	D	21	4.29	1.007
	E	11	4.36	0.674
	F	18	4.39	0.916
	G	19	4.05	1.224
	H	2	4	1.414
	I	7	3.57	1.397
	J	4	3.5	1.732
	K	3	2.67	1.155
	Total	121	4.25	1.075
As you consider the PLTW Master Teacher as well as the Online Core Training content on a scale of 0 to 10 how likely are you to recommend the PLTW Online Core Training experience to another teacher or administrator?	A	10	9.6	0.699
	B	7	9.71	0.756
	C	21	9.19	1.123
	D	21	8.24	1.609
	E	13	8.15	2.734
	F	18	8.83	1.425
	G	20	8.25	2.124
	H	2	7	0
	I	7	7	1.633
	J	4	7.75	2.872
	K	3	5	4.359
	Total	126	8.48	1.942
Have you previously attended an onsite PLTW Professional Development experience?	A	10	0.4	0.516
	B	7	0.43	0.535
	C	21	0.33	0.483
	D	21	0.52	0.512
	E	13	0.62	0.506
	F	18	0.28	0.461
	G	20	0.3	0.47
	H	2	0.5	0.707

	I	7	0.29	0.488
	J	4	0.75	0.5
	K	3	0.33	0.577
	Total	126	0.4	0.493
Have you previously attended an online PLTW Professional Development experience?	A	10	0.1	0.316
	B	7	0.14	0.378
	C	21	0.05	0.218
	D	21	0.05	0.218
	E	13	0.08	0.277
	F	18	0	0
	G	20	0.1	0.308
	H	1	0	.
	I	7	0	0
	J	4	0.25	0.5
	K	3	0	0
	Total	125	0.06	0.246

Note: n = number of participants in a particular cohort, M = means, *SD* = standard deviation

Yolanda Baquet Valencia
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Education:

Johns Hopkins University: Doctor of Education (Ed.D.) 2016 - 2021
Specialization: Technology Integration in K-16 Education

Endicott College: Master of Education (M.Ed.) 2000 - 2001

Northeastern University: Bachelor of Science (B.S.) 1996 - 2000
Major: Biology
Minor: Secondary Education

Professional Experience:

Johns Hopkins University Center for Talented Youth 2020 - present
- Online Science Instructor

Gulliver Academy 2003 - 2017
- Science and Engineering Chair (2011-2017)
- Engineering Teacher (2010-2017, grades 7&8)
- Physical Science Teacher (2003-2010, grade 8)
- All Girls Engineering (2009-2017)
- Engineering Camp Director (2012-2016)
- Launch Lead Teacher (2014-2017)

Project Lead the Way 2009 - 2016
- Professional Development Facilitator (Gateway Master Teacher)
  - Summer of 2011 – Florida State University
  - Summer of 2012 – Florida State University
  - Summer of 2013 – Sinclair Community College, Oregon Institute of Technology
  - Summer of 2014 – Florida Gulf Coast University

Summit Montessori School – Framingham, MA 2001 - 2003
- Teacher (ages 3-6)

Lexington Montessori School – Lexington, MA 2000 - 2001
- Teacher (ages 3-6)

Mary E. Curley Public Middle School – Jamaica Plain, MA 1999 - 2000
- Teacher (grade 6, science, math)

Northeastern University Center for Cardiovascular Targeting – Boston, MA 1997 - 1999
- Laboratory research assistant